

CHAPTER 5

PROPOSED MFL CRITERIA (Results Section)

The following chapter describes the technical relationships that provide the basis for establishing MFL criteria for the Loxahatchee River and Estuary as required in Chapter 373, Florida Statutes. This chapter provides a summary of the scientific approach and technical relationships that were evaluated in defining significant harm for the water body and includes a detailed presentation of the proposed MFL criteria with supporting documentation.

The purpose of the following sections are to (a) identify technical relationships considered in defining significant harm; (b) provide proposed MFL criteria for the NW and SW Forks of the Loxahatchee River and estuary, (c) identify future MFL research projects need to refine and/or validate the proposed MFL, and (d) provide an overview of the District's proposed MFL Recovery and Prevention Strategy.

TECHNICAL RELATIONSHIPS CONSIDERED IN DEFINING SIGNIFICANT HARM

Sources of Information

Once the water resource functions of the river and estuary that need to be protected by the establishment of the MFL were identified, specific technical relationships were developed and considered to define significant harm for the water body. The following sources of information were reviewed and considered in the development of these criteria:

1. Consideration of policy links and technical relationships considered in other planning efforts.
2. Development of a “Valued Ecosystem Component” (VEC) approach similar to that developed by the EPA (1987) to establish a minimum flow regime that will protect important components of the ecosystem from significant harm.
3. Results of a literature search produced a bibliography containing nearly 90 citations (**Appendix A**) concerning technical relationships among flow, salinity, hydrodynamics and key biological indicator communities and species, for the Northwest Fork, the downstream estuary and similar systems. This review involved (a) identifying individual species or biological communities that could potentially be used as indicators, targets, or criteria for determining a minimum flow for the river and the estuary, and (b) determining how these indicator species or indicator communities have been impacted by historic hydrologic alterations within the watershed.
4. Review of historical aerial photographs from the 1940's (black and white), 1980's and 1995 (color infrared) that quantify and document changes in the distribution of the major wetland and upland communities along the river corridor over time as a result of hydrologic changes and development within the watershed.
5. Review of the results of a river vegetation survey by District staff documenting the distribution of major vegetation communities present along the NW Fork of the Loxahatchee River and Kitching Creek and their relationship to the saltwater-freshwater gradient.
6. Development of an empirical relationship between historical flow and salinity data collected from the river and estuary from January 1997 through July 2000
7. Development of a hydrodynamic and salinity model for the Loxahatchee River and estuary to help predict salinity distribution within the ecosystem as a function of various

flow regimes. The model is a two-dimensional depth-averaged finite element model, developed with the Army Corps of Engineers RMA-2 and RMA-4 codes.

Technical Relationships Identified In Other Planning Efforts

In the development of the Loxahatchee National Wild and Scenic River Management Plan (FDEP/SFWMD 2000), the following technical relationships were identified regarding protection of the NW Fork of the Loxahatchee River.

Loxahatchee River National Wild and Scenic River Management Plan (FDEP/SFWMD 2000), page 37-38.

“...The principal problem affecting the river’s plant communities is the gradual reduction in the number and geographic extent of healthy bald cypress in the floodplain and their replacement by mangroves. Virtually all of the cypress in the lowermost areas of the Wild and Scenic river segment are now dead, and are not reproducing, as are the majority of cypress below Kitching Creek. Above Kitching Creek, the number of live trees increases with increasing distance up the river.

An analysis conducted by the U.S. Geological Survey between 1979 and 1982 [Duever unpublished data] further documented the extent of environmental stress in the cypress trees along the Loxahatchee River corridor. The study examined core samples to identify changes in tree ring width and quality. The results of the study indicated that although all of the trees sampled had experienced stress at periodic intervals over their life histories, the proportion of stressed trees in the downstream section (below river mile 9.0) increased from 30 percent in 1940 to 80 percent in 1982. Stressed trees above river mile 9.0 decreased from 11 percent to 3 percent during the same period. Further, the study found a high correlation between the incidence of growth stress and high salinities in surface water and soils.

Based on this study, and the other available research, it is evident that the decline of cypress in the river is attributable to the upstream movement of saltwater. Occasional inundation by saline surface water probably does not result in serious or long-term effects. Frequent inundation, however, gradually increases the salinity of the floodplain’s peat soils. Since these soils are not readily flushed, the resulting stress gradually spreads to more and more trees. Attempts to identify the principal cause of saltwater intrusion, and to make precise correlations between stress periods and the dates of known effects likely to have affected tree growth, have been inconclusive. Nonetheless, three causes have been identified as contributing factors: (1) insufficient flows to the NW Fork; (2) dredging activities in the river’s estuary and in Jupiter inlet; and (3) the drawdown of groundwater levels by wells in the Jupiter-Tequesta area. Each of these factors must be addressed if the deterioration of the river’s cypress communities is to be reversed....”

Chapter 83-358, Laws of Florida

Section 2. Legislative Declaration

“...The Legislature finds and declares that a certain segment of the Loxahatchee River...possess outstandingly remarkable ecological, fish and wildlife, and recreational values which are unique in the United States. These values give national significance to the river as one which should be permanently preserved and enhanced, not only for the citizens of the State of Florida, but for citizens of the United States, present and future generations...”

Section 3. Definitions—as used in the act

(7) “Resource value” means any one or more of the specific scenic, recreational, geologic, fish and wildlife, historic, or ecological features identified by the National Park Service, Department of Interior in its Draft Wild and Scenic Rivers Study/Draft Environmental Impact Statement as being outstandingly remarkable or worthy of note.

Wild and Scenic Rivers Study/Draft Environmental Impact Statement (U.S.D.O.I./N.P.S., 1982)

Outstandingly Remarkable Ecological Values

Page 3-2 “...The NW Fork of the Loxahatchee River has signs of salt water intrusion as is demonstrated by the presence of mangroves as understory plants to dead cypress trees in the segment downstream from Trapper Nelson’s. However, many of the other rivers in south Florida have been converted over from freshwater swamp to mangroves, because of the implementation of the Intracoastal Waterway and development pressures. The highest value of the Loxahatchee River lies in the fact that the NW Fork is the best remaining example of a South Florida river-swamp. Although portions of the Loxahatchee River were logged for cypress in the early 1940’s, it is still a largely pristine cypress river-swamp. Some of the cypress [trees] are from 300-500 years old. This represents a virtually irreplaceable and unique resource. In relation to the rest of the United States, the diversity of plant species along the Loxahatchee River is remarkable....There are currently no rivers within the National System which even approximate the character of this unique subtropical coastal plain river....”

Page 5-24 “...The NW Fork of the Loxahatchee River represents the last vestige of the native vegetational communities of southeast Florida. Most of the native bald cypress community was harvested by the lumber industry by the 1930’s and only isolated strands of cypress exist in places which were extensive forests. The cypress river-swamp community on the NW Fork of the Loxahatchee River remains largely intact from the pressures of lumbering and development. Many specimens along this reach of the river range from 300-500 years in age, representing an irreplaceable ecological and scenic resource. The cypress river swamp exhibits high species diversity due to the overlap of tropical and temperate zones. Along with cypress, the floodplain harbors maple, water hickory, cabbage palm, pond apple, water oak, and cocoplum. Tropical vegetation such as wild coffee, myrsine, leather fern, and cocoplum may be found along with water [pop] ash, water hickory, red bay royal fern and buttonbush, which are considered examples of more northern flora. Abundant ferns, bromeliads and orchids enhance the lush tropical environment of this reach of the river....”

Valued Ecosystem Component (VEC) Approach

The SFWMD Coastal Ecosystem Department’s research program supports application of a resource-based management strategy defined as the “Valued Ecosystem Component” (VEC) approach. This evaluation methodology is similar to a program developed by the U.S. Environmental Protection Agency as part of its National Estuary Program (USEPA 1987). For the purposes of this study, the VEC approach is based on the concept that management goals for the Loxahatchee River and estuary can best be achieved by providing suitable environmental conditions that will support certain key species, or key groups of species, that inhabit the river system.

In the case of the NW Fork of the Loxahatchee River, the key group of species identified to be protected against significant harm is the bald cypress (*Taxodium distichum*) river-swamp forest and its associated freshwater flood plain community. The VEC approach assumes (a) that environmental conditions suitable for the VEC will also be suitable for maintaining other desirable species and their habitats; and (b) that enhancement of the VEC will lead to enhancement of the entire ecosystem. Through this strategy, management objectives will be attained by providing a minimum flow that will protect the cypress river-swamp community against significant harm.

The VEC approach was applied to the NW Fork of the Loxahatchee River based on the following assumption: Providing a supply of clean freshwater of sufficient quantity and appropriate timing is essential for maintaining the river’s scenic qualities and diverse native plant and wildlife populations. The principal problem affecting the ecology of NW Fork of the river is the gradual reduction in the number and geographic extent of healthy bald cypress in the upstream river floodplain and their gradual replacement by salt-water tolerant mangroves. Virtually all of the cypress communities in the lower most portion of the river (below Kitching

Creek) are either dead or severely stressed by saltwater intrusion. Above Kitching Creek, the numbers of live trees increases with increasing distance upstream (FDEP & SFWMD 2000). Providing a minimum flow that will protect this community from further saltwater encroachment (significant harm) is important for maintaining the river's "Wild and Scenic River" status.

Based on the information presented within this report, there is strong evidence that the decline of cypress communities along the NW Fork of the river is attributable to the gradual upstream movement of saltwater over time. Three primary causes of saltwater intrusion are identified. They include: (1) historical dredging activities of the river's downstream estuary and opening of the Jupiter Inlet; (2) drainage of upstream wetlands (the Loxahatchee Slough) by construction of the C-18 canal, (3) draw down of the local ground water table to provide flood protection for new development and (4) increased pumping of the local aquifer by local well fields in the Jupiter-Tequesta area over the past 30 years.

Upon this basis District staff selected the cypress river-swamp community as the VEC of choice to establish a minimum flow that will protect the river from significant harm. As discussed above, this community represents a number of important water resource functions that need protection during low flow periods. The District has published several studies using this resource-based approach to define optimum freshwater flows that should be delivered to the Caloosahatchee estuary (Chamberlain *et al.* 1995, Chamberlain and Doering 1998a, 1998b).

Literature Review

Sources of Information

One of the requirements for developing a minimum flow for the river is the requirement to use "best available information". The Loxahatchee River has been the focus of numerous studies over the past three decades. A literature review was conducted to review the results of these studies as they may relate to defining a flow/salinity relationship or recommended minimum flow for the Loxahatchee River. Results of the literature review as well as an accompanying bibliography of these studies are provided in **Appendix A of this report**. The literature review is organized chronologically beginning in the early 1970s when the problem of saltwater intrusion in the NW Fork was first identified in the scientific literature as a major public concern.

Summary of Findings

1. The Loxahatchee River and estuary is a small (544 km²) shallow-water body in southeastern Florida that empties into the Atlantic ocean at the Jupiter Inlet. Historical evidence indicates that the estuary periodically opened and closed to the sea as a result of natural causes. Originally, freshwater and tidal flows maintained the inlet open for some of the time. Near the turn of the century, some flow was diverted by construction of the Intracoastal Waterway and the Lake Worth Inlet and by modification of the St. Lucie Inlet. Subsequently the Jupiter Inlet remained closed for much of the time until 1947. After 1947, the inlet was dredged to remain permanently open for navigation (Wanless et al. 1984).
2. Freshwater enters the NW Fork of the Loxahatchee River primarily through four major tributaries. These include flows received from the Loxahatchee Slough and G-92. On average this represents approximately 57% of the total flow (as measured at SR 706) delivered to the

NW Fork, while Cypress Creek contributes another 32%, Hobe Grove Ditch 7% and Kitching Creek, 4% (Russell and McPherson, 1984).

3. In the early 1970's it was recognized that hydrologic alterations of the watershed have reduced freshwater flow delivered to the river causing the upstream movement of saltwater during dry periods as well as saltwater intrusion of the local ground water aquifer (Land et al. 1972, Rodis 1973, Birnhak 1974). The primary cause of observed changes in flora and fauna along the NW Fork of the River was identified as the upstream movement of saltwater during drought periods (Rodis 1973, Birnhak 1974, Alexander and Crook 1975, FDNR, 1985, Duever unpublished, McPherson unpublished). These studies recommended that to maintain and protect the natural communities of the NW Fork, sufficient freshwater should be redirected from inland canals and water storage areas into the Loxahatchee River.
4. Rodis (1973) recommended that a constant freshwater flow of 50 cfs delivered over the Lainhart Dam would be required to restrict the upstream movement of saltwater and preserve remaining natural communities in the middle and upper reaches of the NW Fork. This recommendation included an assumption that other contributing tributaries (Cypress Creek, Hobe Grove Ditch and Kitching Creek) would provide an additional 80 cfs. Birnhak (1974) suggested that flows delivered to the NW Fork of the river within the range of 60 cfs would be sufficient to limit saltwater intrusion of the upstream river system.
5. Alexander and Crook (1975) produced a comprehensive study of the major changes in vegetation that have occurred in South Florida over the last 30 or more years. One of their study plots included an area of the NW Fork of the Loxahatchee River near the mouth of Kitching Creek. Based on photo-interpretation of aerial black and white photos taken from 1940 and 1970 they concluded that since 1940, wet prairie and cypress swamp hardwoods had lost ground to pineland and mangrove communities due to a lowering of the groundwater table and invasion of saltwater between river miles 6 and 8.
6. In the mid 1980's the FDNR (1985) produced a follow-up report to Alexander and Crook's (1975) work. This report showed that many mature cypress trees from river mile 7.0 to 9.0 were dead and the number of trees stressed near river mile 9.0 had increased substantially from 1979 to 1982 as compared to the 1975 study. By 1984, the majority of cypress trees downstream of Kitching Creek (RM 7.8) were observed to be dead (FDNR 1985).
7. Each of these studies identified the presence of a freshwater layer of water overlying denser seawater within the estuary and portions of the NW Fork of the river. This vertical stratification of the water column, or saltwater wedge, is a common feature of estuaries. The upstream tip of the saltwater wedge is characterized as a bottom salinity that exceeds 2 parts per thousand (Russell and McPherson 1984, Mote Marine Lab, 1990) as shown in simplified conceptual diagram below (**Figure 12**). Salinity studies conducted within the river (Russell and McPherson, 1984) indicate the average distance of the salinity wedge between top and bottom is approximately 0.5 miles (**Figure 12**). During periods of reduced freshwater input, the saltwater wedge may extend as far as 5 to 10 miles upstream of the NW Fork. The saltwater wedge was reported to move daily from 0.5 to 1.5 miles up and down the river in response to freshwater inflow and daily tidal fluctuations (Russell and McPherson, 1984).
8. Russell and McPherson (1984) conducted an intensive study of the relationship of salinity distribution and freshwater inflow in the Loxahatchee River estuary from 1980-1982. Freshwater inflows to the major tributaries were measured at six continuous gauging stations including the NW Fork of the Loxahatchee River, Cypress Creek, Hobe Grove Ditch, and

Kitching Creek. Results of this study calculated the total amount of freshwater [from all sources] needed to restrict brackish water (2 ppt) from the upstream reaches of the NW Fork at mean high tide. The values are shown in **Table 13**.

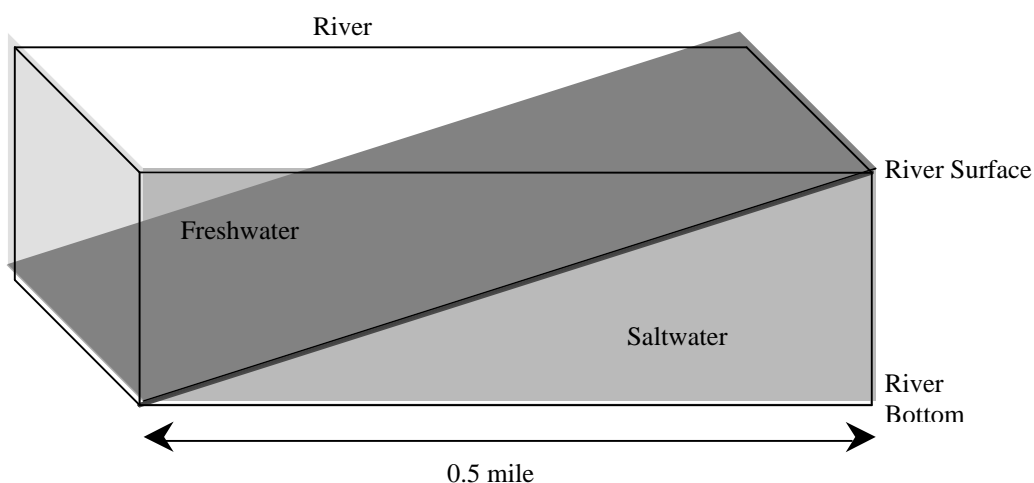


Figure 12. Conceptual diagram of the saltwater wedge

9. Based on the flow/salinity relationships provided in **Table 13**, the total amount of freshwater (from all sources) needed to restrict the saltwater wedge from the upstream reaches of the river was determined to be 120 cfs at river mile 8.2 (located upstream of the confluence of Kitching Creek and the NW Fork of the river). Of this total flow, 57% (or about 68 cfs) is derived from the NW Fork, 32% (38 cfs) from Cypress Creek, 7% (8 cfs) from Hobe Grove Ditch, and 4% (5 cfs) from Kitching Creek (Russell and McPherson, 1984). The authors of this report also noted that maintaining the above flow regime would not protect the river under all conditions. During extreme high tides and storm events, saltwater could still move upstream for brief periods.

Table 13. Total mean daily discharges to the NW Fork of the Loxahatchee River and corresponding upstream extent of the saltwater wedge in river miles (Russell and McPherson 1984)

Total* Mean Daily Freshwater Discharge (cfs)	Upstream extent of saltwater wedge in river miles
220	7.0
130	8.0
120	8.2
75	9.0
43	10.0
26	11.0

* Includes NW Fork + all upstream tributaries

10. Law Environmental (1991) summarized unpublished SFWMD flow, salinity and rainfall data collected from 18 sites within the NW Fork and downstream estuary from 1985-1988. Average and median flows discharged to the NW Fork of the river through G-92 were

recorded as 50 and 56 cfs, respectively over the 3-year study. Average bottom salinity recorded at river miles 9.2, 8.0, 6.9, and 5.7 were 0.4, 2, 8, and 17 ppt, respectively. Vertical stratification of the water column was most prominent at river miles 2.6 and 8.0. Under extreme low flow conditions the salinity wedge was transported upstream by slightly more than one river mile. Under these low flow conditions, average bottom salinity recorded at river miles 9.2, 8.0, 6.9, and 5.7 were 3, 13, 17, and 25 ppt. Surface and bottom salinity at river mile 8, located within the area of cypress die-off, was less than 0.2 ppt and 0.4 ppt for 50% of the 1985-1988 data set. Discharges from S-46 were reported to have substantial effects upon salinity regimes many miles upstream of the NW Fork. The report concluded that salinity control by a regulated freshwater discharge at average flow conditions of 40 to 50 cfs could benefit the ecosystem by establishing a stable salinity wedge location for the estuary system.

11. McPherson and Halley (1996) in their publication, *The South Florida Environment: A Region Under Stress*, documented the encroachment of mangroves, along with the overall reductions in freshwater flows, maintenance of lower groundwater levels, short duration high volume freshwater flows for flood protection, and changes in the quality of runoff.
12. More recent studies conducted by Dent and Ridler (1997) indicate that flows delivered to the NW Fork of the River (as measured at SR 706) that are equal or below 50 cfs, may not be sufficient to maintain freshwater conditions as far downstream as RM 8. Their data indicated that over a one-year monitoring period, the 50 cfs target was met only 33% of the time. When flow was equal to or less than 50 cfs, bottom salinity exceeded 2 ppt upstream of water quality station #65 (RM 8.6) 95% of the time while water quality station # 64 (RM 7.7) exceeded 2 ppt 100% of the time. This report proposed a minimum flow rate of 75 cfs (as measured at SR 706 bridge) for the end of the dry season (May) and 130 cfs for the wet season (July-November). They also recommended a maximum flow range, i.e., discharges should not exceed 150 cfs during the months of February-May, and no greater than 300 cfs during the wet season (June-November).
13. Dent and Ridler (1997) also provide information as to the sensitivity in which salinity concentrations within the river react to changes in flow. For example at water quality station # 65 (RM 8.6), a drop in the upstream flow rate from 150 cfs to below 60 cfs over a five day period resulted in the almost immediate movement of salt water into the area.
14. As late as 1998, the original USGS flow target of 50 cfs established by Rodis (1973) was still identified as the recommended minimum flow target for the NW Fork. The origin of this target was based on water flowing over the Lainhart dam; a broad crested weir located 0.1 mile north of SR 706. Previous flow rating curves developed for the dam in 1984 tended to under estimate flow over the dam. The dam was reconstructed in 1998 and flow-rating curves developed for the dam tended to significantly over estimate discharge. For this reason District staff conducted a re-calibration of the rating curve for the Lainhart dam in 1998. Re-calibration of the dam and subsequent statistical review of this new flow/salinity information resulted in the recommendation that a minimum flow target of 64 cfs was needed to maintain the saltwater wedge (as 2 ppt bottom salinity) just downstream of the confluence of Kitching Creek and the NW Fork of the river (SFWMD 1999).
15. Salinity studies were conducted to determine the effects of physical modifications to the river and estuary, such as filling man-made gaps between the winding oxbows in the NW Fork. Analysis of salinity data collected before and after the barriers were installed indicate that by

redirecting the flow of the river through the original meandering oxbows of the river, approximately 0.7 RM were restored to the distance for saline tidal waters to move upstream (Dent 1997).

16. Several studies recommended consideration of the construction of a saltwater barrier to reduce the upstream movement of saltwater during dry periods.

Historical Changes in River Vegetation Communities

District staff utilized existing historical aerial photography to compare changes in the distribution and abundance of vegetation communities along the floodplains of the NW Fork of the Loxahatchee River over time. Black and white aerial photos taken in 1940 were compared to color infrared photography taken in 1995 to quantify changes in the coverage of major vegetation communities. Special focus of this investigation was to assess changes in the distribution and abundance of freshwater hardwood (cypress) communities and mangrove communities along the river corridor through time. In addition, District staff re-examined several sites along the NW Fork of the river originally documented by Alexander and Crook (1975) during their investigation of long-term changes in South Florida vegetation communities. The purpose of this work was to document changes in vegetative cover through time and correlate these changes to major events or changes within the watershed.

The 1940 aerial black and white photos were obtained from the National Archives (College Park, Md.). The 1995 color infrared Digital Ortho Quad photographs were obtained from National Aerial Photography Program. Groundtruthing and field observations were conducted by District staff to validate the signatures of the current plant communities found along the floodplain of the river. **Appendix B** of this report provides the reader with a detailed summary of the methods, results, and river vegetation maps developed as part of this investigation.

Historically the Loxahatchee watershed consisted primarily of coastal hammock, pine flatwoods, seasonal ponds and prairies, freshwater swamp, hardwood forests and mangroves. A large portion of this vegetation remains today due to earlier military and agricultural uses with subsequent land use changes to large tracts of public conservation and recreation and agricultural lands, and 5 to 10 acre ranchettes under private ownership. The NW Fork has been provided with additional protection as portions of this water body have been designated as a federal wild and scenic river. The oldest municipality is the Town of Jupiter, which was incorporated in 1925. Neighboring municipalities Juno Beach, Jupiter Inlet Colony, Jupiter Island, Palm Beach Gardens, and Tequesta were all incorporated during the 1950s (**Table B-1 Appendix B**). Today the primary land uses are public conservation and recreation, agriculture, and residential development.

1940 Vegetative Cover

Figure B-2, Appendix B, provides a summary of the major vegetation communities found along the NW Fork of the river in 1940 based on a review of historical black and white aerial photographs. **Table 14** summarizes these coverages (in acres) of each community type for 1940 and 1995.

Results show a relatively undeveloped watershed in 1940. According to the 1940 U.S.

Census, the Town of Jupiter contained 215 residents (**Table B-2, Appendix B**). Interstate 95 and the Florida Turnpike had not yet been constructed. The major roads which existed were Center Street, State Road 706 (Indiantown Road), State Road 710 (Beeline Highway), U.S. Highway 1, State Road 708 (Bridge Road) and Northlake Boulevard. The C-18 Canal also did not exist at that time, although there was evidence of ditching southward to the Loxahatchee and Hungryland Sloughs. The Jupiter Inlet was open in the 1940 photograph, but the presence of sandbars probably reduced the amount of saltwater coming in during high tides. The inlet was not permanently stabilized for navigation until 1947. On the NW Fork, incoming tides reached upstream past the mouth of Kitching Creek frequently enough to encourage mangrove growth along the fringe of the river ending at RM 7.8 on the northern bank.

The most obvious features of the 1940 aerial photographs are the abundance of wetlands associated with sloughs and wet prairies and the lack of urban development throughout most of the watershed.

Table 14. Vegetation coverage for years 1940 and 1995 for NW Fork of Loxahatchee River

1940 Vegetation	Coverage (in acres)	1995 Vegetation	Coverage (in Acres)	% Difference
<i>Freshwater Plant Communities</i>				
Swamp Hardwood (Cypress)	467.21	Cypress	128.06	-73%
Inland Ponds & Slough	58.55	Inland Ponds & Slough	38.63	-34%
		Stream Swamp	188.37	
		Freshwater marsh	8.09	
Cabbage Palm	3.08	Cabbage Palm	4.3	+139%
Ornamental	1.44	Ornamental	0.64	-55%
<i>Sub-total</i>	530.28		368.09	-31%
<i>Saltwater Tolerant Plant Communities</i>				
Mangrove	163.06	Mangrove	154.74	-10%
<i>Other</i>				
Disturbed or Cleared Lands	26.82	Disturbed or Cleared Lands	83.61	+212%
<i>TOTAL</i>	729.55		608.55	-17%

The three main tributaries of the river and the surrounding lands resemble a cross section through a kidney with the river acting as the main outgoing duct, while the uplands and sloughs resemble a network of interconnecting sinuses (**Figure B-1, Appendix B**). There are extensive wetlands (prairies and four major sloughs) between Kitching Creek, the North Fork of the river, and Bridge Road in Martin County. Two of the sloughs appear to connect the North and NW Forks. All four sloughs would have provided a source of freshwater that is not present today. Of the four sloughs, only Wilson Creek remains connected to the river today. Other visible hydrologic characteristics identified in the 1940 photographs included:

- On the NW Fork, Hobe Grove Ditch did not exist in 1940, but Moonshine Creek was apparent and drained a wetland slough to the north
- No citrus was grown near the river as it is today, but there was extensive land clearing north of SR 706 on the east side of the NW Fork perhaps for agriculture

- A wetland slough connected Jones Creek to Lake Worth Creek (in the vicinity of what is today Frenchmen's Creek)
- Jones and Sims Creeks were lined with mangroves south of SR#706
- The SW Fork was a small meandering creek dominated by mangroves
- The SW Fork/Limestone Creek had been ditched but not channelized
- Mangroves bordered the North Fork and transitioned into freshwater vegetation in the vicinity of today's park boundary (north of the Girl Scout Camp). The floodplain was very narrow in the mangrove areas
- There were very few mangrove islands in the embayment area
- Spoil mounds were evident along the Lake Worth Creek and the lower Indian River Lagoon from the dredging of the Atlantic Intracoastal Waterway channel

An estimate of the location of Interstate 95 and the Florida Turnpike was made to define the southern boundary of the study area. The clarity of the black and white photography was not distinct enough to identify specific tree species within the freshwater canopy (with the exception of concentrated areas of cabbage palms). Because the dominance of cypress could not be validated, the category of "Swamp Hardwood" from Alexander and Crook's (1975) study was used to identify these freshwater communities in the 1940 photographs. **Table 14** shows that in 1940, there were about 163 acres of mangroves and 467 acres of swamp hardwoods within the floodplain. Of the total 730 acres of vegetation identified in the 1940 aerial photography (**Table 14**), more than 64% was represented by the swamp hardwood (cypress) community while mangroves represented about 22% of the vegetative cover. Disturbed or cleared land represented 26.2 acres or about 4% of this coverage. The area of ornamental vegetation includes an exotic ornamental plant garden (1.4 acres) established by Mrs. Alice De Lamar.

1995 Vegetative Communities

Beyond the obvious publicly owned lands and agricultural fields, the eastern portions of the Loxahatchee River Watershed were highly urbanized in the 1995 photographs (**Figure B-2, Appendix B**). A 1999 census estimate showed the Town of Jupiter with a reported population of 33,925 residents within the city limits. Jupiter residents plus neighboring municipalities accounted for a population of 77,484 residents (**Table B-2, Appendix B**), however, this figure does not include the residents of unincorporated Palm Beach County in the western portion of the watershed. Interstate 95 and the Florida Turnpike stand out as major features that bisect the landscape along with extensive areas of agriculture (primarily citrus and cattle grazing), and the 11,471 acres of Jonathan Dickinson State Park.

The most striking features noted in the 1995 aerial photography was the dredge and fill of former mangrove islands between river miles 4.5 and 5.5 of the NW Fork and the loss of floodplain due to development and the placement of bulkheads along both shorelines of the estuary and lower NW Fork of the river. Along the upper NW Fork, upland species (i.e. saw palmetto, slash pine, etc.) appear to have invaded the floodplain. Also, the islands and oxbows of the NW Fork appear to have been heavily scoured over the last 55 years. This is apparent in total acreage differences between the 1940 and the 1995 coverages. There is a loss of approximately 121 acres of vegetation in the floodplain over this 55-year period (**Table 14**).

Figure B-3, (Appendix B) illustrates the 1995 distribution of vegetation within the floodplain. Color infrared photography allowed for the identification of a greater number of plant categories and better observation of vegetative changes. In 1940, mangroves were dominant

between RMs 4.5 and 6.5 and were present up to RM 8.5. Fifty-five years later, mangroves had progressed upstream as the dominant vegetation in the floodplain between RMs 5.5 and 8.6. Between RMs 8.6 and 10, they share the floodplain area with cypress and other freshwater hardwoods. In 1995, mangroves are present within the lower portion of Kitching Creek. Near the mouth of the creek, the mangroves appear as forests whereas further upstream they appear as understory vegetation with a cypress canopy. In 1995, there were approximately 155 acres of mangroves and 368 acres of freshwater vegetation (**Table 14**) along the NW Fork (east of Interstate 95 and the Turnpike). In this case, freshwater vegetation consisted of stream swamp (188 acres), cypress (128 acres), and freshwater marsh (8 acres).

Between 1940 and 1995, mangroves exhibited losses and gains in total coverage (**Table 14**). Approximately 84 acres of mangroves were lost due to development of formerly mangrove islands between RM 4.5 and 5.5. Mangroves increased 149 acres from establishment on cleared lands (6%) and from invading freshwater communities (32%). The gains in coverage occurred primarily between RMs 6.0 and 8.5. Approximately 165 acres of mangroves remained unchanged over the 55-year period.

There was no overall increase in freshwater vegetation over the study period. Infrared photography allowed for the identification of freshwater marsh associated with the wider floodplain areas. Losses of freshwater hardwoods have occurred due to colonization by mangroves, scouring of the river, lumbering activities, and changes in the hydroperiod. Results of a field survey of the river showed that many of the remaining freshwater marsh areas have been invaded by the exotic Old-World climbing fern, *Lygodium microphyllum*. Review of available information suggests that mangroves had taken over areas that were formerly freshwater marsh. There was a net loss of 149 acres of freshwater habitat (i.e., mangroves increased), primarily between RMs 6.5 and 7.8 (**Appendix B**). Within the remaining freshwater communities along the open river (RMs 9.0 to 10.5) there were changes in the signature of the canopy. Whereas the 1940 black and white photographs had exhibited a very uniform canopy among swamp hardwood areas, the 1995 photographs exhibited a canopy of more varying heights, colors and textures. Field observations and geographical coverages showed that while there were remaining areas of greater than 50% cypress, other areas consisted of a mixture of freshwater dependent hardwoods including red maple (*Acer rubrum*), water hickory (*Carya aquatica*), laurel oak (*Quercus laurifolia*), pond apple (*Annona glabra*), pop ash (*Fraxinus caroliniana*), dahoon holly (*Ilex cassine*), and bay (*Persea spp.*). These areas were designated as “stream swamp” in the 1995 coverage. Changes within the freshwater communities (i.e., increases in diversity and a loss of cypress as the dominant species) suggest that there has been a change in the hydroperiod to less frequent inundation of the floodplain. This is reflected by the 1995 distribution of mangroves and freshwater coverages in the Hobe Grove Ditch and Cypress Creek areas (**Figures B-4 and B-5, Appendix B**). Areas dominated by cypress appear to be more closely associated with wider floodplains suggesting that there may be less species competition and less water stress associated with these areas. Other visible hydrologic or structural changes noted in the 1995 photographs included:

- The SW Fork was channelized between 1957 and 1958 to create the C-18 Canal and leaving very few remaining mangroves.
- C-14 and the G-92 Structure were constructed in 1974 to redirect water from the Southwest Fork to the NW Fork
- Over 3,000 acres of citrus groves have been planted west of the NW Fork

- Hobe Grove Ditch was dug through uplands to provide flood control for citrus groves during the 1960s. Surface water flowing from this area during dry periods is now being retained to maintain the water table for these irrigation wells.
- Most of the remaining inland ponds and sloughs appear to be much smaller in size in comparison to the 1940 photographs

Comparison to Previous Studies

The 1973 field observations of Alexander and Crook (1975) provide a historical record of the existing floodplain vegetation in several locations along the NW Fork and Kitching Creek. In Alexander and Crook's (1975) study, Site 10 was located on Kitching Creek, while Sites 13, 14, and 15 were located on the NW Fork (**Figure B-6, Appendix B**). A comparison of the interpretation of 1940 vegetation from historical aerials revealed similar results. Alexander and Crook (1975) interpreted Site 10 as a swamp hardwood dominated by water oak, maple, ash, and pond apple. Sites 13 and 14 were interpreted as mangrove river communities, while Site 15 was interpreted as a cypress canopy with a mangrove understory. In our interpretation of these same areas (**Figure B-6, Appendix B**), Sites 10 and 15 were still swamp hardwoods, while Site 13 was predominately swamp hardwood with a small amount of mangrove at the southern tip. Site 14 was predominately mangrove with some cleared land. For their 1973 field observations using 1970 black and white aerials, Sites 14, 15, and most of Site 13 are shown as mangrove river communities. Within Site 10, swamp hardwoods are shown to be present just outside of the mouth of Kitching Creek. Field surveys of these same areas were groundtruthed by District staff in November 2000. Their results recorded the following changes in river vegetation:

- Site 10 – (Kitching Creek) mangroves are present up to the second bend in the creek and occur further upstream as understory. Freshwater communities were a mixture of cypress, stream swamp, and freshwater marsh. The largest freshwater marsh area is dominated by small pond apples with an understory of sawgrass and ferns
- Site 13 - almost completely mangrove. A small remnant of the live cypress remains on the northern boundary adjacent to the uplands probably due to its distance from the riverbed and influence of the adjacent ground water.
- Site 14 - a large red mangrove island with leather fern and string lily (*Crinum americanum*) understory, has not changed except the tree heights no longer reach 30 feet
- Site 15 - predominately mangrove with the only live cypress remaining along a northeastern ridge and some concentrated areas of cabbage palms found on another ridge area

Impacts of Hydrological Alterations and Meteorological Events on Vegetative Changes

Odium et al. (1982) noted that one generally unrecognized side effect of lowered freshwater flow and saltwater intrusion has been the inland expansion of mangrove forest. The examples that were given included the mangrove borders of Biscayne Bay and much of the Everglades. These forests have expanded inland since the 1940s in conjunction with man's alteration of surface and groundwater flows. Red mangroves are particularly very successful invaders. Their rod-shaped propagule promotes very efficient tidal transport, they have the lowest seedling mortality rate compared to other mangrove species, and they have the ability to grow in freshwater environments. In addition, these studies indicate that floating red mangrove propagules remain viable up to 12 months. A similar invasion of mangroves has taken place on

the Loxahatchee River.

The opening and closing of the Jupiter Inlet, the reduction of surface water flows delivered to the river due to drainage and development of the region, coupled with lowering of the groundwater table has promoted the distribution of mangroves and reduced the freshwater habitat of the NW Fork of the Loxahatchee River. Saltwater intrusion in the river has produced major changes in the freshwater vegetative communities. In many areas, mangroves now dominate former freshwater cypress habitats. Intrusion has produced additional changes within remaining freshwater communities to favor the expansion of species that are better adapted to dryer conditions and are more salt tolerant.

Hurricanes have affected the watershed by producing rises in tidal levels, opening and closing of inlets, changes in topographical and land contour and by producing severe physical damage to vegetation. Major hurricanes and tropical storms occurred in the vicinity of the Loxahatchee in 1928, 1933, 1981. Hurricanes have also been known to spread plant propagules over long distances with their waves and high tides.

Severe droughts were recorded in 1937/38, 1943/44, 1950/51, 1955/56, 1960/61, 1966/67 and 1970/71, 1980/81 and 1989/90. Droughts affect vegetation through "water stress" and saltwater intrusion. Cypress seeds require flooding for a number of months before germination may take place. Research on living cypress tissue suggest that saline water produces an excess accumulation of sodium and chloride, which may affect different processes within the plant.

Severe frost winters were reported in 1939-40, 1957-58, 1962-63 and 1964-65 (Alexander and Crook, 1975) and in 1977, 1983, 1985 and 1989 (FDEP, 2000). Mangroves do not tolerate below freezing temperatures for any length of time and may defoliate after exposure to temperatures less than 45°F. This may partially explain why mangroves along the NW Fork do not reach the height of mature mangroves found in more southern locales where they can grow to up to more than 60 feet in height.

Although mangroves have replaced a considerable amount of the downstream historical coverage of freshwater vegetation along the NW Fork of the Loxahatchee River, the Wild and Scenic River segments of the waterway continue to be a valuable natural resource and tourist attraction with both mangrove and cypress habitats.

Summary

At this time, District staff is in the process of examining additional low altitude infrared photographs taken in 1985 for changes in the distribution of floodplain vegetation. Results of the comparison of 1940 and 1995 aerial photographs showed the following:

- The 1940 Loxahatchee River Watershed had an abundance of swamps, wet prairies, marshes, inland ponds and sloughs and mangroves. Within the upper portions of the watershed the freshwater riverine system connected to small creeks and streams and occasionally to the Everglades system.
- In 1940, there was very little agricultural or urban development within the watershed and the Jupiter Inlet periodically opened and closed.
- 1940 aerial photography revealed that there was about 163 acres of mangroves and 467 acres of swamp hardwoods in the floodplains. Sixty-four percent of the floodplain habitat

consisted of freshwater hardwoods such as cypress, while 22% of the vegetative cover was mangrove.

- Comparison between the 1940 aerial photographs and the 1995 infrared photographs revealed highly developed landscape within the Loxahatchee River watershed, although the natural areas located within Jonathan Dickinson State Park remain still intact.
- Mangroves exhibited both gains and losses over the 55-year period. In the 1995 photographs, there were approximately 155 acres of mangroves and 368 acres of freshwater vegetation. Approximately 84 acres of mangroves were lost due to the development of formerly mangrove islands within the floodplain, while mangroves increased in extent (149 acres) by invading freshwater communities and becoming established in disturbed or cleared lands.
- In 1940, mangroves were dominant between RMs 4.5 and 6.5 and present up to RM 7.8. By 1995, mangroves had become the dominant floodplain vegetation between RMs 5.5 and 8.6 and are present upstream through RM 10. They have also invaded the lower portions of Kitching Creek.
- Between 1940 and 1995, freshwater vegetation showed no true gains in vegetative coverage. There was a 75% decrease in swamp hardwood communities, which consist primarily of bald cypress.
- Changes within freshwater communities were reflected by a loss of cypress dominance along the immediate river corridor upstream of RM 9 reflecting the impact of saltwater intrusion at this point in the river. Areas dominated by cypress appear to be impacted by groundwater flow from uplands and wider floodplains, which protect their roots from saltwater.
- Comparisons of Alexander and Crooks' (1975) investigations revealed similar results for 1940 vegetative coverage and a steady increase in the invasion of mangroves since their 1973 field inspections of several sites along the NW Fork and Kitching Creek.

Field Vegetation Survey Results for the Northwest Fork

District staff conducted a field vegetation survey of the NW Fork of the River and Kitching Creek in November 2000. This survey was performed to document the changes in river corridor vegetation communities as they relate to the observed freshwater-saltwater gradient. The following is a summary of those findings.

Figure 13 provides a general summary of the major vegetation community boundaries (or zones) observed along the river corridor as recorded in November 2000. This map was developed utilizing field vegetation survey observations to ground truth the vegetation communities identified in 1995 aerial photographs. These zones include (1) "Dead Cypress", (2) "Dead and Stressed Cypress", and (3) "Healthy Cypress".

The "Dead Cypress" zone, located downstream of RM 8.9 on the NW Fork, consists of scattered individuals and stands of dead mature cypress "snags" (defoliated trees consisting of tree trunks with/without remaining primary branches); and sparse to moderate coverage of scattered individual cabbage palms and palm stands, with small canopies; and dense coverage red mangroves.

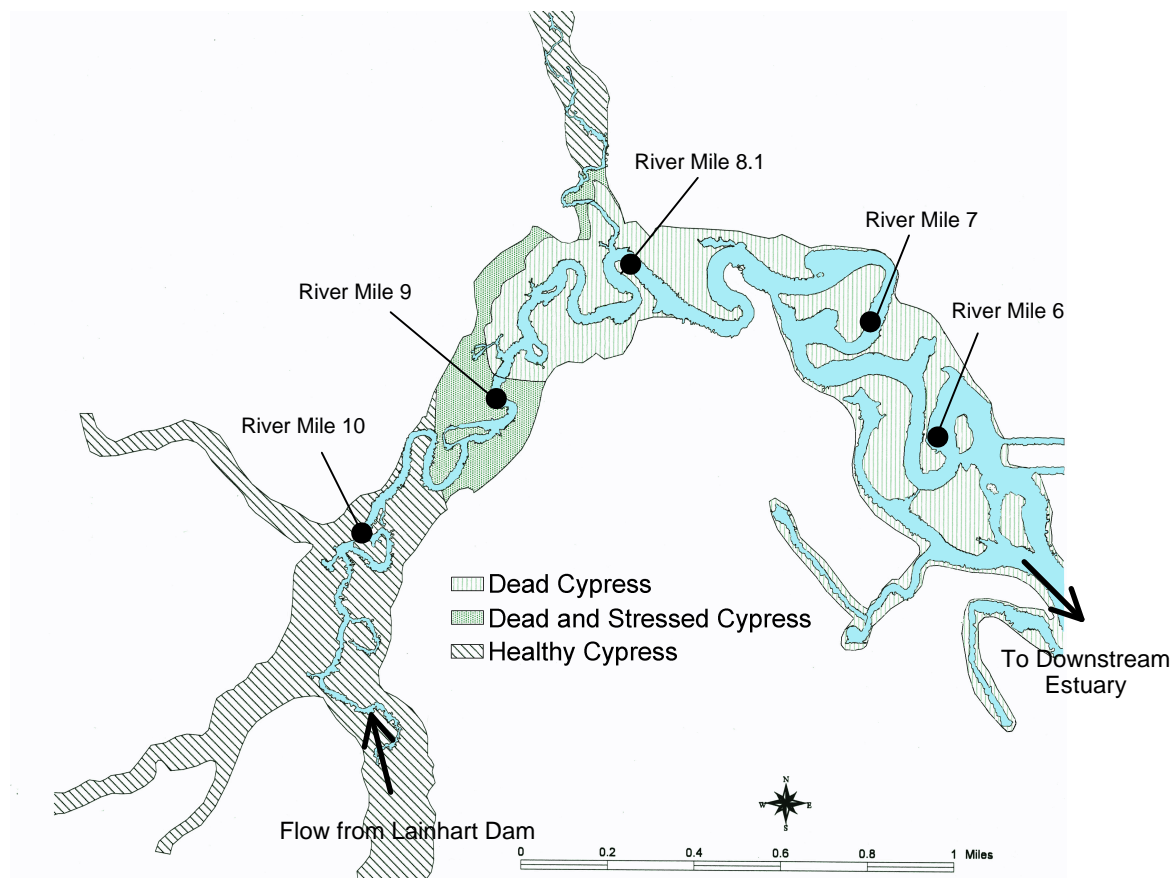


Figure 13. Major Vegetation Zones and River Miles identified for the NW Fork of the Loxahatchee River, November 2000.

The “Dead and Stressed Cypress” zone, located from RM 8.9 to RM 9.3 on the NW Fork, consists of sparse to moderate coverage of stressed live mature cypress trees (trees with very sparse and/or partially dead canopy and primary and secondary branches, and dead portions of trunk) intermixed with dead cypress; sparse to moderate coverage of scattered individual cabbage palms and palms stands, with small to moderately sparse canopies; dense to moderate coverage of red mangrove understory; and sparse coverage of a diversity of brackish water tolerant plant species.

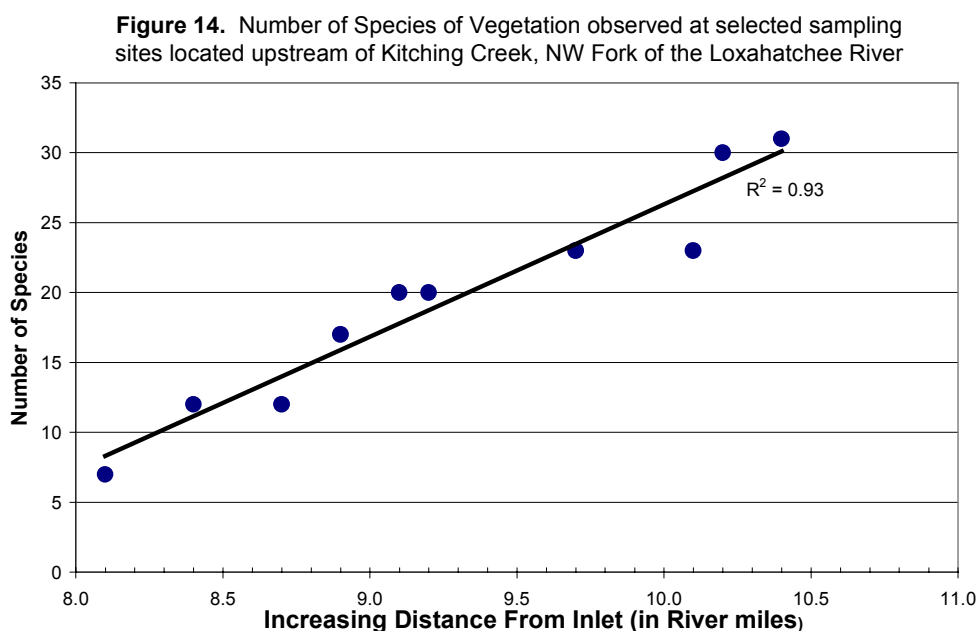
The “Healthy Cypress” zone, located upstream of RM 9.3 on the NW Fork, consists of: moderate to dense coverage of healthy live mature cypress stands; may be intermixed with moderate to dense coverage of diverse freshwater wetland plant species; and sparse coverage of scattered individual cabbage palms. The “Healthy Cypress” zone, located upstream of RM 9.3 on the NW Fork, consists of: moderate to dense coverage of healthy live mature cypress stands; may be intermixed with moderate to dense coverage of diverse freshwater wetland plant species; and sparse coverage of scattered individual cabbage palms.

In addition to the development of the generalized vegetation zone map, the field survey also provided the following results:

- Two types of saline-freshwater gradients are found along in the River. The first gradient is associated with the location of a vegetation community and its distance (in terms of river miles) from the Jupiter Inlet. Those communities that are located closer to the inlet are

subject to the increased influence of the daily tidal cycle that originates from the inlet. The second saline-freshwater gradient is associated with a community's proximity to uplands. Several plant communities found along the river are influenced by freshwater groundwater seeps from higher elevation areas. Vegetation distribution changes within the river corridor are evident relative to both of the gradients

- Species lists and abundance were recorded at seventeen sites along the Loxahatchee River. Shoreline, emergent, and submersed vegetation were noted, since they are most affected by saltwater influx. For this analysis, only similar data were compared. Data not considered were those that were collected near the edge of the floodplain (affected by freshwater seepage from uplands) and data collected near the erosive (undercut) shore in an oxbow.
- Results of the vegetation survey reported species abundance and species diversity to be low in the estuarine portions of the River (RM 5 through 7) as compared to upstream freshwater areas of the river. Species abundance and diversity increased dramatically upstream within the river from river mile 8 to 10 as salinity decreased (**Figure 14**). Similar changes in diversity along the freshwater-saline gradient were found in Kitching Creek.



- Vegetation communities near the edge of the floodplain (adjacent to the uplands and subject to freshwater seeps) had greater species diversity than adjacent river segments that were more interior of the floodplain.
- Embankments near the undercut (high energy) shore of a river oxbow exhibited upland species to the river's edge with few, if any, wetland species.
- The abundance of dead bald-cypress "snags" throughout the remaining undeveloped downstream portion of the Loxahatchee River indicate that bald-cypress swamps within the past century had thrived here and grew in response to a largely freshwater regime as compared to present day. These areas are now dominated by saltwater tolerant red

mangroves to at least River Mile 5.5 (vegetation site 5B).

- Examination of dead bald-cypress trees along the river gradient suggests a gradual dieoff rather than a sudden loss from a single event (such as a hurricane storm surge). This is based on the observation of remaining limb and branch structures. Remaining bald-cypress snags located near river mile 5.5 (site 5B) have few primary limbs remaining. Near river mile 6.2 (site 6A) primary limbs and few secondary branches are present. Near river mile 7.5 (site 7B) many primary and secondary limbs persist, indicating a death in more recent times.
- Bald-cypress abundance (live) increases gradually along the river salt water gradient, reaching peak abundance by river mile 10 (**Figure C-1, Appendix C**).
- A bald-cypress/swamp hardwood canopy is present starting in river mile 10 Cabbage palms (live) initially increase in abundance, then decreases as the Bald-cypress/swamp hardwood canopy increases (**Figure C-2, Appendix C**). Red mangrove dominates the vegetation community through approximately river mile 10, then rapidly declines (**Figure C-3 Appendix C**).
- Red mangrove (a tropical, cold-sensitive species) never develops a high canopy (as is seen in southerly parts of the peninsula) since it is regularly pruned back by frost. This makes it sensitive to competition from high canopy species (e.g. bald cypress, pop ash, laurel oak). However, where it is established, it forms a dense thicket and low canopy that effectively out-competes many other species' seedlings.
- Cabbage palms seem to be more salt-tolerant than bald-cypress (**Figure C-1, Appendix C**).
- Laurel oak, red maple, and dahoon holly are more salt-sensitive than bald-cypress (**Figure C-2, Appendix C**).
- An examination of ten sites along Kitching Creek showed trends in vegetation species diversity and abundance similar to those found with the main stem of the NW Fork.

Statistical Relationships Between Flow and Salinity

In an effort to evaluate the relationship between the amount of freshwater flow needed to maintain the salinity wedge at selected points along the NW Fork of the River, regression analyses were conducted using flow and salinity data collected from the river from January 1994 through July of 2000. Specifics as to how these analyses were conducted are found in the methods section (Chapter 3) of this report. Results of the regression analyses and their associated graphical plots are presented in **Figures D-1 through D-5, Appendix D** of this report.

Table 15 and Figure 15 provide summaries of the minimum dry season flow rates that are required to be delivered from the Lainhart Dam to the NW Fork of the Loxahatchee River to maintain a bottom salinity of 2 ppt for selected locations along the river. These results are reported in SFWMD river miles (RM) upstream from the Jupiter inlet.

Table 15. Relationship between Dry Season Lainhart Dam Flow and estimated position of the saltwater wedge within the NW Fork of the Loxahatchee River.

Water Quality Station Number	Upstream Extent of 2 ppt salinity (river miles)	Dry Season discharges from Lainhart Dam (cfs)	
		Total Data Set (Jan 1994-Jul/2000)	After closure of Gaps
WQ Station # 63	6.5	203	236
Avg. of WQ Stations # 63 & 64	7.1	146*	161*
WQ Station # 64	7.7	90	87
Avg. of WQ Stations # 64 & 65	8.1	68*	68*
WQ Station # 65	8.6	47	49
Avg. of WQ Stations # 65 & 66	9.0	31*	32*
WQ Station # 66	9.4	15	15**
WQ Station # 67	10.5	<10	< 10**

* Flows shown were estimated by averaging data between upstream and downstream water quality sampling stations

** Represent upper limit for this value

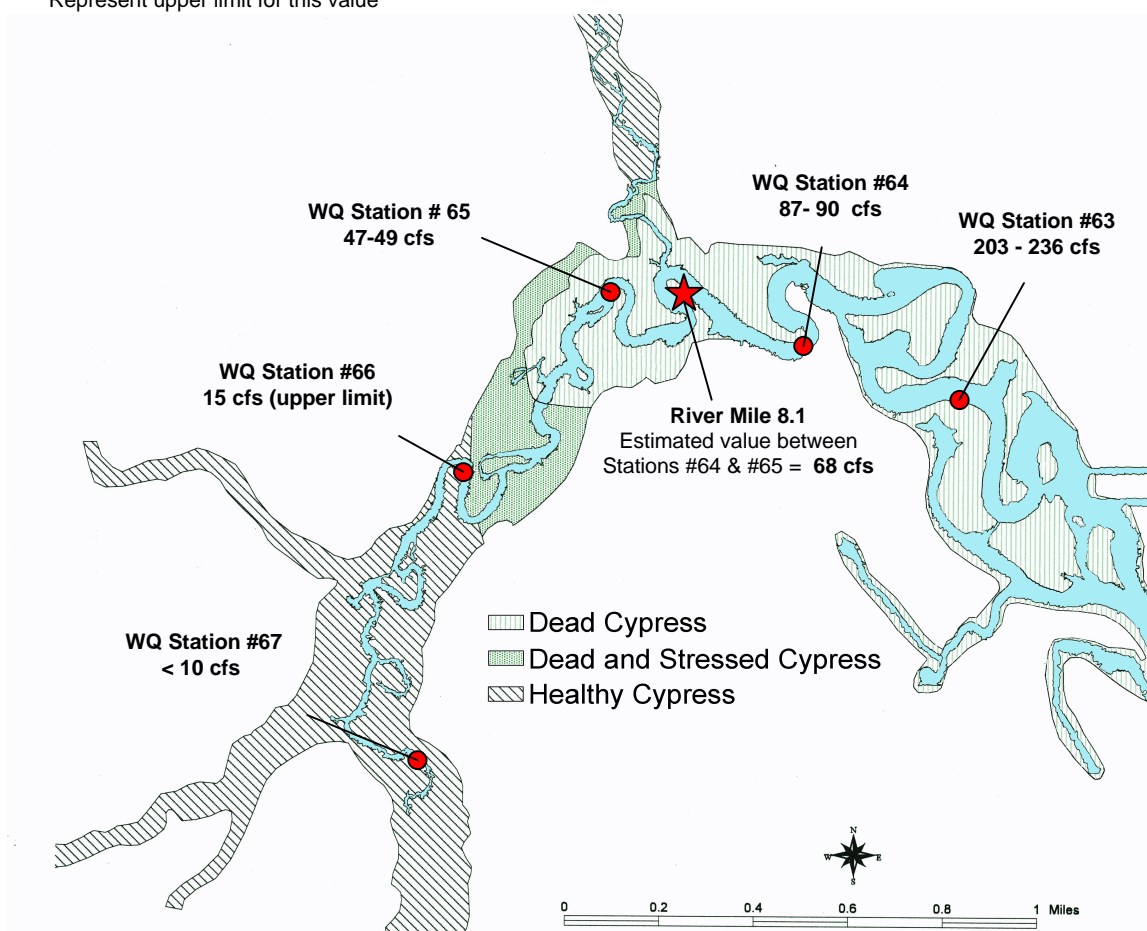


Figure 15. Statistical Results: Amount of flow required from Lainhart Dam to maintain river bottom salinity of 2ppt at selected sites, NW Fork, Loxahatchee River

Water Quality Station # 63 (River Mile 6.5)

Water quality station # 63 (**Figure 15**) is located just upstream from the south boat ramp in Jonathan Dickinson State Park at SFWMD river mile 6.5. This site generally represents the nearest river water quality station adjacent to the central embayment (estuary). This water

quality-monitoring site is directly influenced by the daily tidal cycle and upstream movement of saltwater. Over the three year period of record, daily salinity values ranged from less than 0.4 ppt during high discharge events, to a high of 20-25 ppt recorded during a number of low flow periods. Time series for flow and salinity for each of the five river water quality sampling stations are shown in **Appendix D**.

Results of the regression analyses show that a flow of within the range of 203 -236 cfs would be required from the Lainhart Dam to reduce river bottom salinity to less than 2 ppt at water quality station # 63 (**Figure D-1, Appendix D**). Salinity data recorded from this site exhibited a wide degree of variability as compared to the other upstream monitoring sites. Water quality station #63 showed the poorest correlation between river flow and salinity recording an r^2 of 0.25 for the 1994-2000 data set, and 0.40 after closure of the river gaps in 1997 (**Figure D-1, Appendix D**). This low correlation occurs, in part, because this site is the most downstream monitoring station and is subject to greater daily tidal fluctuations, effects of wind, and major storm events due to its proximity to the ocean at the Jupiter Inlet. In addition, this area may also be subject to the cumulative effects of freshwater seepage from surrounding uplands and other inflows that are not fully accounted for in the estimated river flow.

Water Quality Station # 64 (River Mile 7.7)

This station is located approximately 1.2 miles upstream of water quality station # 63 or about 0.5 mile upstream of the Jonathan Dickinson State Park canoe concession area at river mile 7.7. Because this site is located further upstream within the NW Fork, it showed less variability among data points as compared to water quality station #63 (**Figure D-2, Appendix D**). Seasonal salinity values range from less than 0.1 ppt (essentially freshwater) to 15 – 24 ppt during low flow periods. Review of historical data shows that significantly less river flow is required to maintain the saltwater wedge (**Table 15**) at this site as compared to water quality station #63. At this location, flows within the range of 87-90 cfs are needed from the Lainhart Dam, plus another estimated 10 cfs from other upstream sources, to maintain the salinity wedge at 2 ppt. The estimated dry_season flow contributions for these other upstream tributaries were estimated as: Cypress Creek (7 cfs), Kitching Creek (2 cfs), and Hobe Grove Ditch (1 cfs) based on typical dry season flow values obtained from the USGS study (Russell and McPherson, 1984). Therefore, the total amount of water needed to maintain the salinity wedge at river mile 7.7 is approximately 100 cfs. The correlation between river flow and salinity at water quality station #64 is greatly improved, relative to station 63, with r^2 values of 0.59 and 0.60 reported for this site (**Figure D-2, Appendix D**).

Confluence of NW Fork and Kitching Creek (River Mile 8.1)

River mile 8.1 is located just below the mouth of Kitching Creek about one mile downstream of the “stressed cypress zone” (**Figures 15**). This area was selected as a point of interest because it lies just downstream of the remaining cypress river-swamp habitat that the proposed MFL is designed to protect, and it also lies just downstream of Kitching Creek, an area that still contains significant amounts of cypress swamp habitat. Because no water quality data exists for this site, an estimate was made of the amount flow that needed to be delivered from the Lainhart Dam to maintain river bottom salinity at 2 ppt at RM 8.1. Water quality and flow data from water quality stations #64 (RM 7.7) and #65 (RM 8.6) were averaged together to arrive at 68 cfs as the amount of flow required to maintain the freshwater-saltwater interface at less than 2

ppt at river mile 8.1. $(49 \text{ cfs} + 87 \text{ cfs})/2 = 68 \text{ cfs}$.

It is important to note that during the 1940's Kitching Creek and areas located just upstream from this point in the river supported significant amounts of cypress swamp hardwood habitat as documented in **Figure B-6, Appendix B** of this report. Interpretation of the vegetation studies conducted by Alexander and Crook (1975) show that swamp hardwoods were still the predominate vegetation cover at this point in the river in the early 1970s. Review of 1995 infrared photos (**Figure B-6, Appendix B**) shows that this same area of the river is now dominated by mangroves, most likely a response to increased salinity levels at this point in the river over the past 30 years.

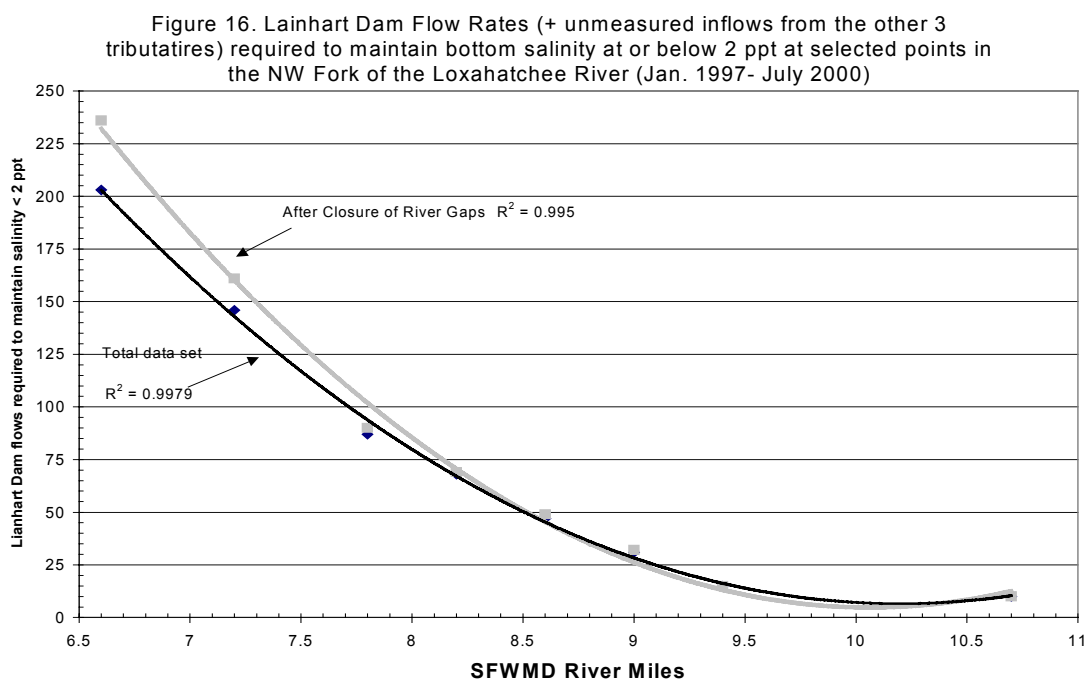
WQ Station # 65 (River Mile 8.6)

Water quality station #65 is located about 0.5 miles above the confluence of Kitching Creek and the NW Fork of the River at RM 8.6. Because this site is located further upstream within the NW Fork, the data shows less variability than what occurs at downstream water quality monitoring sites (**Figure D-3, Appendix D**). Seasonal salinity values range from less than 0.1 ppt (freshwater) to 13 – 19 ppt during low flow periods.

Results of the regression analyses indicate that flow rates within the range of 47-49 cfs are required from the Lainhart Dam to maintain salinity at or below 2 ppt at RM 8.6 (**Figure 15**). This is about 44% less flow required to maintain the salinity wedge at RM 8.6 as compared to water quality station #64 located 0.9 miles downstream.

Water Quality Stations # 66 & 67 (River Miles 9.4 & 10.5)

Review of data collected from water quality stations #66 (RM 9.4) and #67 (RM 10.5) show that during average and high rainfall conditions, these two sites are primarily freshwater. However during prolonged drought conditions, both sites have experienced the saltwater wedge to move long distances upstream within the river within relatively short time periods. **Table 15** and **Figure 15** shows that during prolonged low flow periods (flows less than 10 cfs) the saltwater wedge will penetrate upstream areas of the river as far upstream as water quality station # 67 located just downstream of Trapper Nelson's. Although the number of data points collected from this upstream area of the river are substantially less than the downstream monitoring sites, these data correlate well with previous salinity studies conducted on the river (e.g., Russell and McPherson 1984). Similar results are shown for water quality station #66 where the upper limit of 15 cfs was estimated as the required flow delivered from the Lainhart dam to maintain a salinity of less than 2 ppt at river mile 9.4 (**Figure 15**). Based on the statistical analysis of flow/salinity data discussed above, **Figure 16** provides the general relationship between the volume of water need to be delivered from the Lainhart Dam during the dry season to maintain salinity near 2 ppt at various locations (river miles) along the NW Fork of the Loxahatchee River.



Summary

Results of the regression analysis of historical flow/salinity data show the following:

- At water quality station #63 (RM 6.5) dry season flows within the range of 203-236 cfs are required from the Lainhart Dam to maintain the saltwater wedge (defined as bottom salinity of 2 ppt) at this location (**Table 15, Figures 15**).
- Further upstream at water quality station #64 (RM 7.7), flows within the range of 87-90 cfs are required from the Lainhart Dam to maintain the saltwater wedge at this location.
- At RM 8.1, located just downstream of Kitching Creek it was estimated that a flow within the range of approximately 68 cfs would be required from the Lainhart Dam to maintain the saltwater wedge at this location.
- Approximately one-half mile upstream of Kitching Creek at water quality station #65 (RM 8.6) dry season flows within the range of 47-49 cfs are required from the Lainhart Dam to maintain the salt water wedge at this location.
- At RM 9.0 it was estimated that a flow within the range of 31-32 cfs is required from the Lainhart Dam to maintain the saltwater wedge at this location.
- At water quality stations # 66 and # 67 (RM 9.4 and 10.5) dry season flows within the upper limit range of 10 to 15 cfs would be required from the Lainhart Dam to maintain the saltwater wedge at these locations.

PRELIMINARY MODELING RESULTS

As part of the research effort to establish minimum flow criteria for the Loxahatchee River system, a hydrodynamic model (RMA-2) capable of incorporating the density dependent

effect associated with saline water intrusion was developed for the NW Fork of the River and downstream estuary. The model was used to qualitatively evaluate the flow system sensitivity to factors such as annual tidal variations, canal cross sections, the distribution of inflows along the NW Fork of the Loxahatchee River, and other hydraulic properties. The model's current accuracy is insufficient to warrant using modeling results instead of the field measurements to establish the MFL for the NW Fork of the river even though the measured data does exhibit considerable variation. The model is a useful to in evaluating the importance of factors which are either unmeasured or uncontrollable (or both) in the field measurements. For example the model demonstrates that diurnal and seasonal tidal fluctuations are evident and strongly affect the salinity downstream of river mile 6.5. The long term goals of this modeling effort include the following:

- Providing reasonably accurate (+/- 5 cfs) predictions of salinity expected at various locations within the river for a given amount of freshwater inflows from upstream tributaries incorporating the influence of both daily and seasonal tidal fluctuations within the estuary.
- Provide a tool to develop operational criteria which conserves water (minimizes the volume of water supplied from storage) while meeting the target of maintaining the salinity wedge (as defined by a bottom salinity concentration of 2 ppt) downstream of the confluence of Kitching Creek and the NW Fork of the Loxahatchee River.
- Provide a tool to evaluate river modification such as the installation of a single or multiple submerged weirs to reduce the volume of flow required to maintain the salinity wedge down stream of the confluence of Kitchen Creek and the NW Fork of the river
- Provide a means of evaluating the relatively quick response of the NW Fork due to changes in inflows.

The software used to develop the model was based on the computer programs RMA-2 and RMA-4 developed by the USACE (1996). The RMA-2 is a finite element hydrodynamic numeric model used to simulate water levels and flow within the river and estuary. The RMA-4 is a compatible water quality model designed to simulate depth-averaged advection-diffusion processes in an aquatic environment. RMA-2 and RMA-4 are two-dimensional models that are based on the real topography of the modeling area. In addition to the geographic data, the model also requires flow and tide data to form the boundary conditions. The model requires freshwater inflow data at all tributaries and tide data on the ocean boundary. Wind, precipitation and evaporation have not been included in the model at this stage. Details regarding the use of the model, model assumptions, input data, verification/calibration and model simulation results are presented in **Appendix E**.

Simulation of the Estuary Tidal Cycle

Preliminary model results compare well with collected field data indicating both the estuary and the lower portions of the NW Fork of the Loxahatchee River are strongly influenced by the tidal cycle. The model provides qualitative behavior similar to measured values in the NW Fork upstream of river mile 6.5, however, the stages predicted by the model at Kitchen Creek during low flows are considerably lower than the measured values. In addition, the flows

predicted to maintain the salinity wedge (as defined by a bottom salinity of 2 ppt) are significantly higher than observed. This lack of accuracy is not unexpected and is believed to be due to a lack of cross sectional data and center line elevation used in the upstream portion of the river. The presence of constriction, shoals or a bottom elevation rise can substantially affect the flow regime especially if the bottom elevation rises near or above the mean high tide level.

- Overall, model results suggest that tides cause considerable variation in the position of the 2 ppt isohaline within upstream areas of the NW Fork of the Loxahatchee River
- Model results show a semi-diurnal tidal cycle with two high and two low tides with 6 hours between each high and low tide. This tidal influence can be detected in the model as far as 8-9 miles upstream within the NW Fork of the river. **Figure E-5, Appendix E** provides a graphic showing semidiurnal salinity fluctuations at summary of modeling water quality station #65 (RM 8.6) located on the NW Fork for March 31, 1999.
- Simulation of the monthly tidal cycle includes two spring tides and two neap tides. Spring tides of increased range between high water and low water occur semimonthly as the results of the Moon being new or full. Neap tides of decreased range occur semimonthly as the result of the Moon being in quadrature. **Figure E-6, Appendix E** compares the NOAA predicted tide with Loxahatchee model output at station “BoyScoutDock” for January 1-April 30, 1999.
- Before salinity information could be generated, it was necessary to calibrate and verify the hydrodynamic model to ensure that it correctly generates tidal information. No continuous tidal record could be located for the model calibration and verification period. To address this problem, the model output was compared to the NOAA Tide Book. **Figure E-6, Appendix E** presents both model output and NOAA predicted tides at station BoyScoutDock. Model results showed relatively close agreement between output of the model and the NOAA Tide Book data. Model output was also verified against data of other NOAA sites located within the middle and lower estuary and at the Jupiter inlet.

River Response Times to Salinity Change

The salinity regime of an estuary is a dynamic process. The transition from a freshwater to saltwater regime (and back to freshwater) occurs twice a day in response to changes in tide and freshwater inflow. There is a time lag (response time) between the time of freshwater inflow change and the response of the river to the salinity adjustment. If freshwater inflow is steady after the adjustment, daily salinity variation will stay within a fixed range with the same highs and lows each day. At this point salinity has reached what is termed “a new equilibrium”. **Figure E-7b Appendix E** provides model output showing a continuous flow and salinity record for three locations on the NW Fork of the river. Results show that although it takes 8 to 10 days for salinity to reach a new equilibrium completely, more than 90% of the changes were observed within 5 to 6 days. These results compare well with observed field data (e.g., Dent and Ridler 1997).

Influence of Freshwater Inputs on Salinity

Modeling Approach

Because not all the sources of flow to the river have been quantified, it was necessary to

identify a surrogate flow parameter that could be used to represent freshwater input into the system. For this reason, the model calibration is based on the historic flow record at the Lainhart Dam. This flow record was used as a means to estimate the total freshwater input into the river. Results show that although the model was not able to predict all the fluctuations over the 6-month period, it did reproduce general trends fairly accurate. These results indicate that, under current conditions, flow over Lainhart Dam is the most significant factor in controlling salinity within the NW Fork of the Loxahatchee River during dry periods. During dry periods water is imported from the C-18 through the G-92 control structure (if available and needed). At these times the imported water when added to the seepage from the South Indian River Water Control District (SIRWCD) makes up the majority of the freshwater input into the river. In the model simulations described below, the total freshwater input to the river was linked directly to discharges provided by the Lainhart Dam with appropriate flow ratios applied to the other three tributaries (Cypress Creek, Hobe Grove Ditch and Kitching Creek) as part of the model calibration and verification process.

The model simulation also needed to take into account the effects of tidal range variations within the estuary and river system. Considering that the tidal range variation between spring and neap tides is a major factor that affects salinity within the river system, a 28-day tidal cycle with two spring tides and two neap tides was selected for the model simulation. The model predicts salinity for each of 3000 nodes at 30-minute intervals. To reduce the amount of information for analysis at this level, the model output was limited to provide salinity results for only high and low tide. These results produced 56 high tide salinity and 56 low tide salinity values that were averaged to calculate mean high tide salinity and the mean low tide salinity for the 28-day period. These data were developed for 13 sites located within the NW Fork, the middle and lower estuary, and at the Jupiter inlet.

Modeling Scenario

Simulation #1 was developed using calculations of flow data for the NW Fork and its three tributaries based on historical flow ratios applied in model calibration and verification. Model runs were conducted using the following flow rates discharged from the Lainhart Dam. These rates ranged from 200, 150, 85, 65, 50, 40, 30 and 20 cfs as shown in **Table E-1 and E-2, Appendix E**. In addition to the Lainhart inflows, an additional 10 cfs groundwater and 30 cfs of contribution from the three major tributaries were estimated for average wet season conditions.

Model Results

Output for Simulation # 1 were analyzed to find the "average high tide salinity" and the "average low tide salinity". These results are condensed into color plates as shown in **Figures E-12 and E-13, Appendix E**. These charts include flow and salinity relationships at seven sites located on the NW Fork of the Loxahatchee River. Each colored line on the chart represents one of seven monitoring sites located along the NW Fork of the river. On the horizontal (x) axis of these charts, the amount of freshwater input is represented by the flow rate at the Lainhart Dam, while the vertical (y) axis represents the predicted salinity (in ppt). By the selection of a particular flow rate on the x axis and then drawing a vertical line from that point to the intersection of each colored line (which represents a particular site in the river), one can determine the approximate salinity that would result from that flow rate. Salinities for each of the seven sites can be read from the vertical axis for any given flow regime.

Extrapolation of the results from Simulation #1 at high tide (**Figures E-12 and E-13, Appendix E**) are provided in **Table 16**. These results summarize the amount of water (flow rate) needed to be delivered from the Lainhart Dam to maintain salinity at or below 2 ppt at selected river miles. **Figure 17** plots this relationship both in terms of average high and average low tides. Two parts per thousand was selected as the salinity threshold because it generally represents the leading edge of the saltwater-freshwater interface as it moves up and down the river in response to daily tidal fluctuations (Russell and McPherson 1984).

Based on the results provided in **Table 16**, it would take a sustained flow of approximately 74 cfs from the Lainhart Dam to maintain salinity levels at 2 ppt at river mile 8.1 located downstream of the confluence of Kitching Creek and the NW Fork of the river. This result assumes that flows from the other three tributaries (Cypress Creek, Hobe Grove Ditch, and Kitching Creek) would contribute a total flow volume of approximately 168 cfs to maintain salinity at 2 ppt at this point in the river (**Table 16**).

Table 16. Simulation # 1: High Tide Results - Amount of flow (cfs) required to maintain salinity at or below 2 ppt at seven selected sites located along the NW Fork of the Loxahatchee River

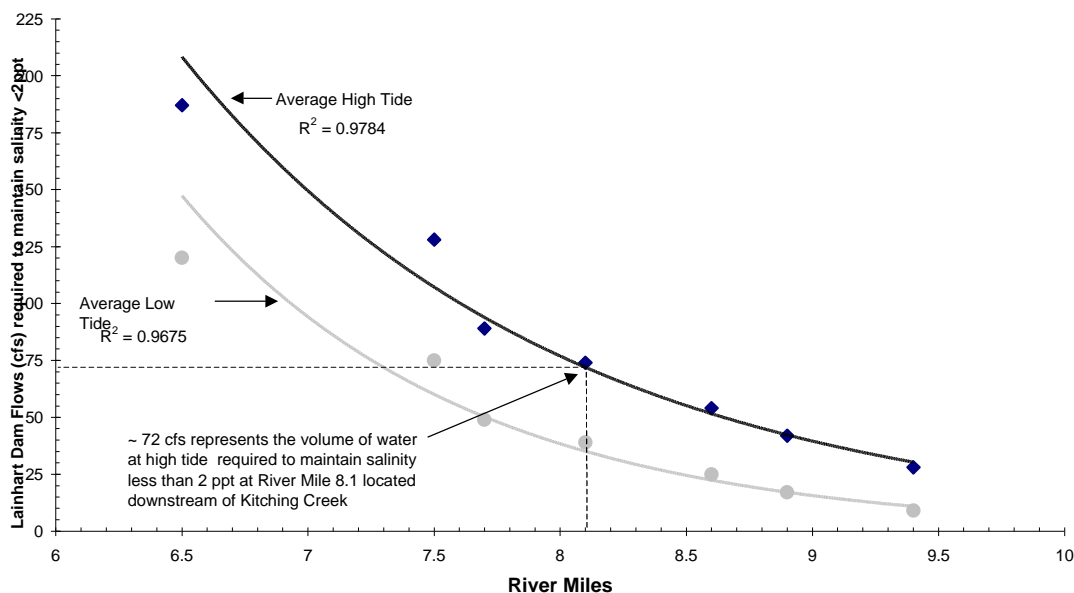
River Mile	Station Name ¹	Estimated Discharge required to maintain salinity below 2 ppt at seven river locations	
		At Lainhart Dam (cfs)	Total Discharge from all tributaries to the NW Fork (cfs)
6.5	WQ Station # 63	187	427
7.5	Veg. Sampling Site 7B	128	291
7.7	WQ Station # 64	89	202
8.1	Veg. Sampling Site 8A	74	168
8.6	WQ Station # 65	54	123
8.9	Veg. Sampling Site 8st	42	95
9.4	WQ Station # 66	28	64

¹= Station locations for the above sites are shown in **Figures 11 & 15**.

Examination of the model output expressed as a regression plot (**Figure 17**) shows that at river mile 8.1 the flow needed from Lainhart Dam to maintain the salinity wedge at high tide at this location in the river is approximately 72 cfs. This value is within the same range as reported for the statistical analysis of field data collected from the river as previously discussed in this chapter (“Statistical Analysis of Flow/Salinity Data”). These results indicate that the two approaches (statistical analysis of field data and model simulation) are providing approximately the same results.

Maintaining salinity less than 2 ppt at this location in the river is important because it represents the transition zone between areas upriver that contain cypress communities that are currently stressed by periodic exposure to high salinity levels, and downstream areas which have been severely impacted by saltwater intrusion

Figure 17. Simulation # 1: Average High & Low Tide Results for the NW Fork of the Loxahatchee River



The location of river mile 8.1 is shown in **Figure 18**. Providing sufficient freshwater flows that will maintain salinity levels less than 2 ppt at this point in the river provides a buffer area that will protect the upstream cypress community against the threat of salt water intrusion (i.e., significant harm) that results from spring tides that periodically push seawater further upstream (one mile or more) in excess of average conditions. **Table 16** and **Figures 17 and 18** illustrate the amount of water that would be needed to maintain salinity levels at or below 2 ppt at selected downstream locations within the river. For example at river mile 6.5 (water quality station #63), it would take a significantly larger volume of water of water (approximately 187 cfs) delivered from the Lainhart Dam plus inflows from the other three tributaries to maintain salinity at or below 2 ppt at river mile 6.5. It is important to note that McPherson (unpublished data) concluded that the original cypress forest community most probably never extended much further downstream than his Site 7E (approximately river mile 5.5, RM) on the NW Fork. **Table 16** indicates that in order to restore this lost habitat down river to mile 6.5, it would require discharges near 190 cfs from the Lainhart Dam plus another estimated 400 cfs from the other three tributaries to restore freshwater habitat to this area of the river. Clearly, restoration of this portion of the river is outside the scope of the MFL statute and the primary objective of this report (to provide a definition of significant harm for the river). These data do however provide a management tool that could be used to define the amount of water needed to maintain the salinity wedge at various locations in the river.

Model Assumptions:

- 1) Values represent position of freshwater- saltwater interface based on flows measured at the Lainhart Dam
- 2) High tide salinity averaged over 28 day lunar cycle
- 3) Model assumes 40 cfs groundwater input
- 4) Percent of flow contributed by each tributary is provided in Tables E-1 and E-2, Appendix E

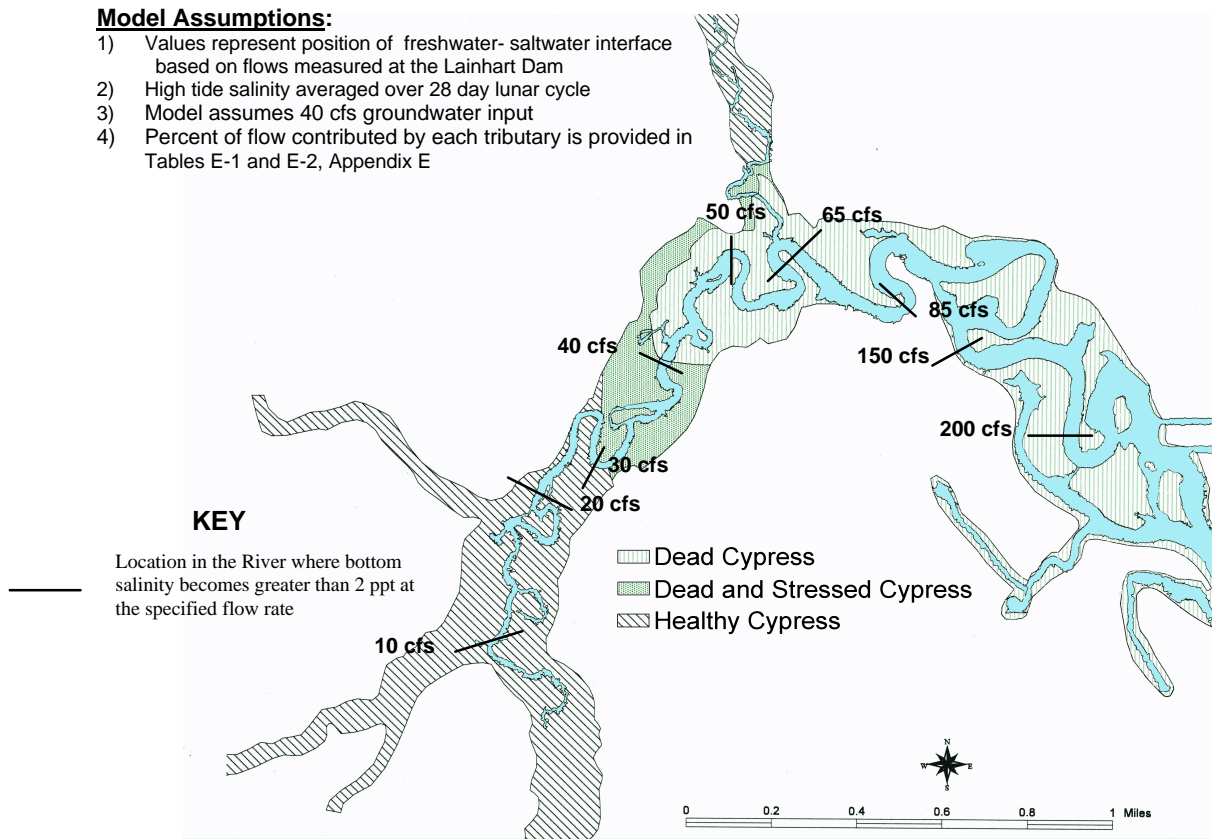


Figure 18. Preliminary Model results for Simulation #1: Amount of flow required to maintain salinity less than 2 ppt at selected sites located along the NW Fork of the Loxahatchee River.

Preliminary results of the model simulation as it affects the NW Fork of the river are presented in a simplified map as shown in **Figure 18**. The purpose of this map is to provide policy makers and members of the public with an understanding of the relationship between flows delivered to the river (measured at the Lainhart Dam) and their effect on maintaining the position of the freshwater-saltwater interface at high tide at various locations within the river system. For example, **Figure 18** shows that flows within the range of 200 cfs delivered over the Lainhart Dam will push the freshwater-saltwater interface downstream past the Jonathan Dickinson State Park boat ramp to river mile 6.0. In contrast, low flows within the range of 10 cfs or less will allow saltwater to penetrate up river as far as the Trapper Nelson interpretive site at river mile 10.5.

Summary

Results of the modeling effort indicate the following:

- Both field data and model simulations show that it is acceptable to use the freshwater inflow rate at the Lainhart Dam as a surrogate indicator of the total freshwater input to the Loxahatchee River system.
- The model output provide reasonable estimate down stream of river mile 6.5 and it generally agrees with the results of previous field measurements and long term salinity records obtained from the estuary. The model provides more qualitative information further upstream due to the lack of cross sectional data. These results indicate a clear correlation between

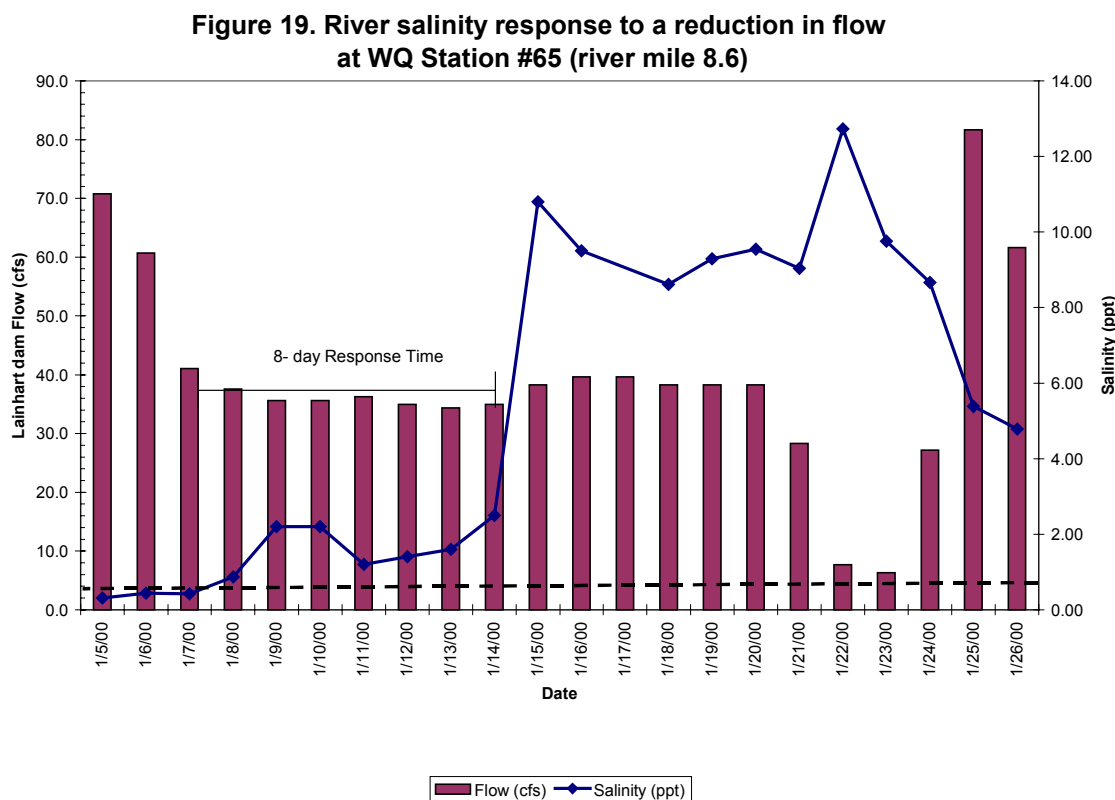
salinity conditions at specific locations within the river and freshwater inflows provided by the Lainhart Dam.

- The upstream portion of the NW Fork of the river appears to be especially sensitive to changes in freshwater input. Both field data and modeling results show that change of freshwater input as small as 10 cfs can cause detectable salinity changes within the river.
- River response times to a reduction in flow indicates that it only takes 8 to 10 days for the river to complete the transition to a new salinity equilibrium. However, more than 90% of these changes occur within a 5 to 6 day period. These results are comparable to reported field data.
- Results of the model simulation shows that a flow rate within the range of 72-74 cfs as discharged from the Lainhart Dam is necessary to maintain salinity less than 2 ppt downstream of Kitching Creek (river mile 8.1). This result also requires that an additional 94 cfs would be required to be delivered from the other three upstream tributaries (Cypress Creek, Hobe Grove Ditch and Kitching Creek) to maintain salinity less than 2 ppt at river mile 8.1 (**Table 16** and **Figure 17**).
- The flow/salinity relationships described in this model simulation, when combined with the results of biological studies, could provide a scientific basis for system management and decision making.
- The model assumption used for ground water input into the system was a constant 40-cfs (i.e., 10 cfs for each tributary). This assumption is the first step in bringing groundwater into consideration as part of the modeling process. As better information becomes available, the model can be improved to determine the role that groundwater plays in maintaining the salinity balance for the river.
- Precipitation and evaporation are not simulated in the current model. While this is acceptable for relative comparisons, precipitation and evaporation should be included as the next step to improve model accuracy.
- These preliminary modeling results have been highly summarized. The dynamic nature of the system response is not fully reflected in the charts and graphs provided in **Appendix E**. The original model contains an extensive amount of information (much of it animated) that describes the dynamic process involved in maintaining salinity regimes within the river and estuary.
- The modeling results presented here focus primarily on the NW Fork of the Loxahatchee River. The model coverage also includes the the middle and lower estuary including the North and SW Forks of the river. The model can also be used to simulate salinity conditions in these areas.

RIVER RESPONSE TO REDUCTIONS IN FLOW

Dent and Ridler (1997) provide insight regarding the sensitivity of the location of the saltwater wedge to reductions in river flow. They reported that at water quality station #65 (RM 8.6), "...a drop in the upstream flow rate from approximately 150 cfs to below 60 cfs over a period of five days resulted in the almost immediate movement of saltwater into the area. As the flow increases again to near former levels, the saline waters are pushed downstream away from the site...." These data compare well with District staff's review of flow/salinity data collected from the river. **Figure 19** shows flow and salinity values collected from water quality station #65 for the month of January 1999. During this time period flows recorded at the Lainhart Dam were reduced from 65 cfs to 35 cfs over a 20-day period. Salinity increased significantly from < 1 ppt

to 11 ppt within an 8-day period (**Figure 19**). Review of flow/salinity data from other points in the river show similar trends -- a fairly rapid response to reduction in flow occurs generally within a 5 - 8 day time frame.



Review of modeling output from the Loxahatchee hydrodynamic-salinity model showed similar results. One model run was specifically developed to evaluate the effects of reducing flow and recording the effects of salinity increases at specific locations within the river. In this simulation, flows were reduced from 65 cfs to 30 cfs at the Lainhart Dam for a 28 day period. **Figure E-1, Appendix E** presents the results of this simulation at river miles 8.1, 8.9, and 9.4. These results show that it takes approximately 8-10 days for the model to reach a new salinity equilibrium, however more than 90% of the salinity change occurred within a 5 to 6 day time period. Response times were also affected by tide regime. The simulation was based on mean tide with a 2.46 ft. range as recorded at the Jupiter Inlet.

Based on review of the above information, the response of the river to changes in flow occurs fairly rapidly, generally within a 5 to 8 day time period. This is an important observation in that the proposed minimum flow will also need to include a “duration” component, i.e., the estimated period of time that the minimum flow criteria may be exceeded without causing significant harm to the upstream cypress river swamp community.

PROPOSED MFL CRITERIA FOR THE NORTHWEST FORK

Minimum Flow Requirements

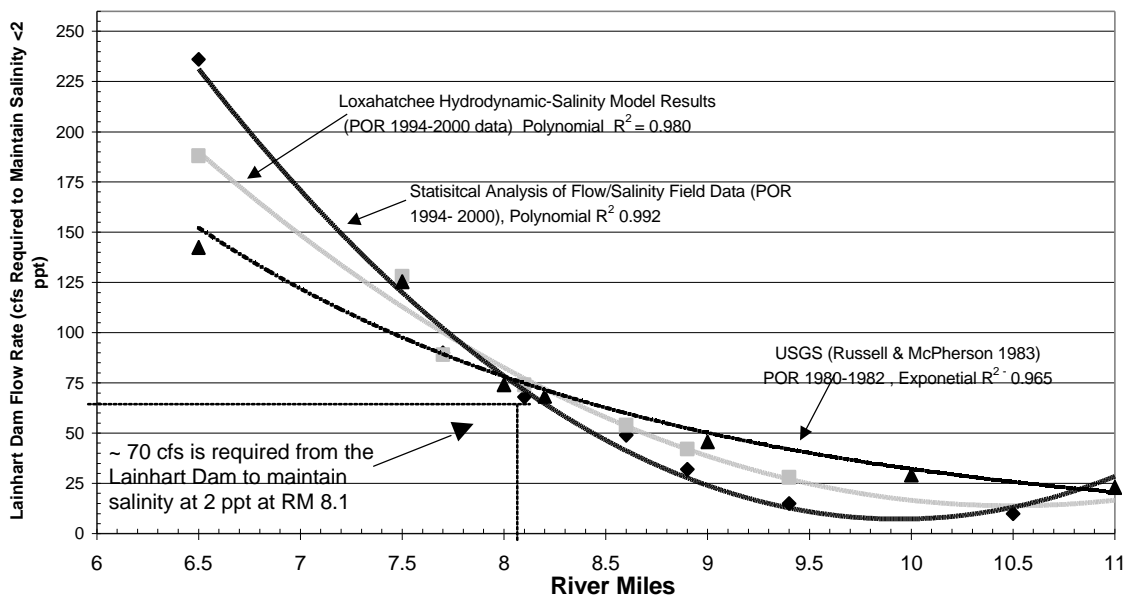
Based on the information presented in this report, minimum flow requirements are recommended for the NW Fork of the Loxahatchee River based on the following assumptions and interpretation of data.

1. In order to minimize significant harm to the NW Fork and its remaining upstream cypress swamp communities, a minimum flow regime should be established near river mile 8.1 (just downstream of Kitching Creek) as shown in **Figure 13**. The rationale for selection of this location is based on the fact that in the 1940's, and as recently as 1970, a healthy cypress river swamp community was observed to be present at this point in the river (Alexander and Crook, 1975). Evidence presented in this study shows that since that time living cypress trees have retreated approximately one mile upriver and have been replaced by saltwater tolerant red mangroves (**Figure B-6 Appendix B**). Selection of this point in the river to establish the MFL is proposed to provide a buffer area between the downstream saltwater influenced areas of the river and remaining upstream cypress river swamp community. This buffer area is needed to (a) protect the cypress river swamp against spring tides that periodically push seawater further upstream (one mile or more) in excess of average conditions, and (b) to protect existing cypress habitat that is present within Kitching Creek.
2. Review of the literature has documented a number of recommended minimum flow rates for the NW Fork of the river. These recommendations ranged from 50 to 75 cfs and include:
 - A minimum continuous flow of 50 cfs (23,000 gallons per minute) across the Lainhart dam was recommended by Rodis (1973) to retard further upstream movement of saltwater in the river
 - Birnhak (1974) recommended that 60 cfs would be sufficient to retard saltwater intrusion of the river.
 - Russell and McPherson (1984) provided the first detailed analysis of the amount of water needed to maintain the saltwater wedge at key locations in the river. They recommended a total mean daily discharge of 130 cfs at what they determined to be river mile 8.0, and 120 cfs at river mile 8.2. Water budgets provided in their report indicated that the NW Fork provided about 57% of the total flow delivered to the river. Based on that flow ratio, the minimum amount of water delivered over the Lainhart Dam to the NW Fork to would range from 68 to 74 cfs at their river miles 8.2 and 8.0, respectively.
 - Dent and Rider (1997) concluded that during dry periods, a minimum flow of 50 cfs may not be sufficient to maintain the saltwater wedge downstream of water quality stations #64 and #65 (river miles 7.7 and 8.6). They proposed a minimum flow rate of 75 cfs for the NW Fork of the river (as measured at the SR 706 bridge) for the end of the dry season (May), and 130 cfs for the wet season (July-November).
 - Re-calibration of the Lainhart Dam by District staff in 1998 and analysis of this new information resulted in a more accurate picture of the relationship between the amount of water discharged over the dam and maintaining the salinity wedge at key points along the river. Results of these analyses indicated that a minimum flow target of 64 cfs was needed to maintain the saltwater wedge (as 2 ppt bottom salinity) just downstream of the point at which Kitching Creek flows into the NW Fork of the river (river mile 8.1)
3. Statistical analysis of the most current (January 1994 - July 2000) set of historical river flow/salinity data indicated that at river mile 8.1, a flow of approximately 68 cfs (plus inflows from the other three tributaries) would be required from the Lainhart Dam to maintain the salt water wedge below this location in the river. Approximately one-half mile upstream of Kitching Creek at water quality station # 65 (river mile 8.6) dry season flows near 50 cfs would be required to maintain the saltwater wedge below this location. Further

downstream at station # 64 (river mile 7.7), flows within the range of 90 cfs would be required to maintain the saltwater wedge at this location (**Figure 15**).

4. Preliminary model results presented in this study indicate that dry season flows delivered from the Lainhart Dam within the range of 72-74 cfs would be required to maintain the salinity wedge at river mile 8.1 (**Table 16** and **Figure 17**). This recommendation comes with the caveat that an additional 94 cfs would be required to be delivered to the NW Fork from Cypress Creek, Hobe Grove Ditch and Kitching Creek to maintain salinity less than 2 ppt below river mile 8.1. These values compare well with Russell and McPherson's (1984) work as well as empirical values presented in this report. It should be noted that the 72-74 cfs minimum flow value was generated using spring tides as part of the model assumption and therefore would be expected to produce flow values slightly higher than average conditions.
5. **Figure 20** provides a comparison between these three investigations of flow and salinity for the NW Fork of the Loxahatchee River as presented in this report. These include: (a) results of Russell and McPherson's (1984) work conducted from 1980 - 1982, (b) statistical analysis of flow/salinity data collected from January 1994- July 2000, and (c) preliminary results from a hydrodynamic-salinity model developed for the Loxahatchee River and estuary. Comparison of these three studies indicates that flows within the range of approximately 70 cfs are required from the Lainhart Dam to maintain the salinity wedge below at river mile 8.1.

Figure 20. Comparison of Three Flow/Salinity Studies for the NW Fork of the Loxahatchee River



Based on these results, the minimum flow rate recommended to prevent significant harm to the remaining cypress communities located along the NW Fork of the Loxahatchee River is approximately 70 cfs of supplemental flow to maintain the salinity wedge downstream of river mile 8.1.

Minimum Duration Requirement

Ideally the proposed minimum flow criteria should also include a minimum duration component (i.e., number of days that the proposed minimum flow may be exceeded without causing significant harm to upstream vegetation communities). To date our understanding of river hydrology and the biology of this ecosystem is not at a level that provides a science-based determination of what this value should be for the NW Fork of the Loxahatchee River. In later section of this chapter, District staff propose a number of research projects designed to specifically determine the ecological risk versus duration of exposure for the cypress swamp community and their associated soils to various degrees of saltwater contamination. The following provides a summary of what is currently known about the response of the river to reductions in flow and increased saltwater contamination:

1. Review of historical flow data shows a number of instances when the river has experienced flows less than 70 cfs for more than 100 days duration. These events have resulted in saltwater penetrating the upstream river system as far as 11 miles, well within the remaining “healthy cypress zone” as shown in **Figure 13**. Events such as these, in combination with lowered ground water tables, are thought to have played a major role in the loss of cypress habitat along the NW Fork of the river.
2. Review of previous studies and modeling results presented in this report shows that the river responds fairly rapidly to a reduction in flow (e.g., from 65 to 35 cfs), generally within a 5-8 day time period. Under this reduced flow regime, the saltwater wedge can move upstream a distance of approximately 1.0 – 1.5 river miles.
3. A key question that remains unanswered is: Once the saltwater wedge moves into upstream areas of the river, how long does it take for saline water to penetrate the floodplain groundwater system and impact the roots of the bald cypress community? Review of flow data collected from 1988-2000 indicates that on average, it takes approximately 22 days (\pm 15 days) for river flows to drop from 65 cfs to less than 30 cfs during an extended dry period. Based on model results presented in this report and review of Russell and McPherson’s (1984) earlier work, a continuous discharge from the Lainhart Dam within the 30 cfs range would allow saltwater to penetrate as far as 9.0 miles upstream which is within the remaining “healthy” cypress zone. Allowing saltwater to penetrate this far upstream would set up the opportunity for saltwater contamination of the floodplain groundwater system that could potentially result in stress or mortality to the remaining bald cypress community. Such an event would be considered significant harm to the water resources or ecology of the area.
4. For this reason the minimum flow criteria should also include a duration component that identifies number of days that the proposed minimum flow criteria may be exceeded without causing significant harm to the upstream cypress community. District staff recommends that flows delivered to the NW Fork of the river as measured at the Lainhart Dam should not fall below 70 cfs for no more than 20 consecutive days to protect the upstream cypress community against significant harm. The 20 day minimum duration criteria is recommended as a place holder until better information becomes available.
5. In consideration of this initial target, District staff recognizes that a number of factors remain unknown regarding the proposed duration component. These include:

- There is a lack of information regarding the ability of the saltwater wedge to penetrate the floodplain water table to the extent that it could potentially cause stress or mortality to cypress trees. Several studies have been initiated in the past to determine the salt content and salinity gradients within the Loxahatchee River floodplain soils and shallow ground water, but results of these investigations are either incomplete, unavailable or unpublished (Roberts, personal communication; Worth, personal communication). During normal rainfall periods base groundwater flows delivered to the river would theoretically provide a freshwater head that would prevent saltwater from penetrating these floodplain soils. However, during an extended drought period, the groundwater table may be reduced to a level that would allow saltwater to contaminate these freshwater soils. It is unknown what groundwater elevation would allow saltwater to migrate from the river to contaminate these soils and impact living cypress trees. This process is thought to be a relatively slow, measured in terms of weeks rather than days.
- There is also uncertainty as to what level of saltwater contamination of the groundwater system would result in significant harm. To establish the effects of elevated salinity on cypress trees, probably two salinity thresholds need to be considered: (a) the acute threshold which identifies salinity concentrations necessary to directly kill a mature cypress tree after one exposure, and (b) the chronic threshold where cypress seedlings or mature cypress trees are killed after prolonged exposure to relatively low salinity levels. Genetic variability of cypress trees grown under different salinity regimes may also be another factor.
- There is no research regarding the physiological salinity threshold of cypress trees for the Loxahatchee River Basin. Several studies from other areas provide some information as to the salinity tolerance of cypress seedlings. For example, Pezeshki *et al.* (1987), Allen *et al.* (1994) and Krauss *et al.* (1999), performed experiments on cypress seedlings from Louisiana and found that acute salinity effects takes place above 2 ppt salinity. These experiments did not adequately cover chronic effects of exposure to salinity ranges less than 2 ppt and therefore should not be used to describe the minimum threshold salinity level for cypress.
- The size and root depth of floodplain vegetation are another a consideration that may influence their susceptibility to saltwater intrusion. Older plants may be more resistant to the direct effects of salt, but, if they have deeper roots, may be exposed to higher concentrations of salt in the soil. Several factors can influence root depth. Generally, larger plants have deeper roots, but the depth of root penetration may be limited in certain areas by the presence of a hardpan or rock layer, or the existence of anoxic conditions, near the surface. Similarly, there are no data from the Loxahatchee River cypress community concerning the depth of the root zone or the relationship between cypress tree size and depth of root penetration.
- Additional research is needed to determine effects of salinity on cypress trees of different sizes, effects of groundwater levels and saltwater intrusion in the floodplain, salt content of floodplain soils at different depths and distances from the river, and the depth of cypress root penetration

Definition of Terms

The proposed MFL criteria consist of three components: (1) a recommended minimum flow delivered to the NW Fork of the river, (2) a duration component that identifies how long the

minimum flow criteria can be exceeded, and (3) the potential for causing significant harm to the environment. These terms are defined below:

- **Minimum Flow** - The minimum flow rate that is sufficient to maintain the freshwater-saltwater interface below river mile 8.1 within NW Fork of the Loxahatchee River the protect upstream cypress river swamp community from significant harm during periods of deficient rainfall.
- **Duration** - The estimated period of time that the minimum flow criteria may be exceeded without causing significant harm to the upstream cypress river swamp community.

Best scientific evidence indicates the NW Fork of the Loxahatchee River has experienced significant harm and degradation of resources primarily due to the combined affects of the following factors.

- The dredging of the Jupiter Inlet and the associated increase in estuary salinity due to tidal flushing.
- Construction of the C-18 Canal reduced the volume of water stored within the Loxahatchee Slough (historically the primary source of water for the NW Fork of the river) and redirected this water to the SW Fork of the Loxahatchee estuary.
- General lowering of the ground water table as a result of drainage and development of the basin has also contributed to less water directed to the river during dry periods
- Documented observations over the last 50 years of cypress mortality and loss of cypress habitat combined with the upstream expansion of saltwater tolerant mangroves provides indirect but compelling evidence that the NW Fork of the river is currently experiencing significant harm.
- Best available information indicates these observed changes are the result of saltwater intrusion of the upstream freshwater portion of the river during dry periods.
- Both the severity and the extent of these impacts are expected to continue into the future (albeit at a very slow rate) unless a minimum flow can be provided that will impede saltwater from entering the upstream river system during dry periods

Based on the information provided in this report, the following criteria are recommended as the minimum flow target for the NW Fork of the Loxahatchee River to protect the upstream reaches of the river and its associated cypress swamp against further degradation due to saltwater intrusion during dry periods. These criteria are intended to provide the minimum amount of water needed to stop the progressive destruction of cypress trees and to prevent additional areas from becoming degraded. These criteria are not intended, and clearly are not sufficient, to restore the river to its condition before dredging of the inlet and channelization of the Loxahatchee Slough by the C-18 Canal.

District staff recommends that during drought periods, the total amount of freshwater delivered to the NW Fork of the Loxahatchee River from all sources should be within the range of 90-100 cfs to maintain a bottom salinity of 2 ppt at river mile 8.1 (located downstream for Kitchen Creek). During mild drought periods (and at the end of normal dry seasons) the other three tributaries (Cypress Creek, Hobe Grove Ditch, and Kitching Creek) and groundwater inflows are expected to provide approximately 20 cfs of flow. Approximately 70 cfs of

supplemental flow will be needed to maintain the salinity wedge downstream of river mile 8.1. During drought periods Jupiter Farms (SIRWCD) is expected to provide approximately 5 cfs leaving a demand of about 65 cfs to be met by importing water from the C-18 via G-92. Under current operating conditions, the District can only import water from the C-18 basin to the NW Fork of the river via G-92 and the Lainhart Dam. Flows delivered to the river by the other three tributaries are primarily rain-driven and do not currently contain gauges, or water management structures that can measure or control the amount of water delivered to the river. Based on this information the proposed MFL for the NW Fork of the Loxahatchee River is:

Criteria for Protection of Cypress Habitat within the NW Fork of the Loxahatchee River

Surface water flows delivered to the NW Fork of the Loxahatchee River from the Lainhart Dam during dry periods shall not fall below 70 cubic feet per second for more than 20 days duration unless monitoring of the salinity wedge (defined by a river bottom salinity concentration of 2 parts per thousand) documents that inflows from other tributaries are sufficient to maintain the salinity wedge at or downstream of river mile 8.1

In consideration of the proposed criteria, District staff recognize the following:

- Under current conditions, the Loxahatchee Slough and Lainhart Dam cannot alone provide sufficient water to meet the MFL on a continuous basis. A portion of this flow must be provided by the other three tributaries (i.e., Cypress Creek, Hobe Grove Ditch and Kitching Creek).
- Improved water management and understanding of the local hydrology are needed within the other three tributaries to help develop a water budget for the river system that can be used to help meet the proposed MFL.
- Additional work is needed to provide a better estimate of the amount of flow required to be delivered to the river from ungauged tributaries and groundwater sources. This additional information will provide a better estimate of the amount of water available within the basin to maintain salinity at the desired level as well as the role that each tributary plays in meeting the proposed MFL. Estimates provided in this report and in other studies indicate that these flows may range from a minimum of 10-20 cfs (extreme dry season) to as much as 60-90 cfs under average conditions. These ungauged tributaries may play a significant role in the District's ability to maintain the salinity wedge at the desired location.
- Management options are available to seasonally vary the amount of water discharged from G-92 and the Lainhart Dam to the NW Fork of the river, depending on the contribution from other sources and the amount of water available in storage. For example, during the wet season the MFL may be met at river mile 8.1 based on higher flow contributions from Cypress Creek and Kitching Creek, thus reducing the dependence on Lainhart Dam inflows. Under this scenario, excess water could be stored upstream within the Loxahatchee Slough to be delivered to the river the following dry season.
- Until additional sources of water are available (see MFL Recovery and Prevention Plan), operational protocols need to be developed to provide available water to the river during dry periods. For example, during an extreme dry period it may be more effective to provide some (even a reduced) rate of flow to the river rather than no flow during drought periods.

It may be desirable to provide a flow rate of 35 cfs for four months rather than 70 cfs for two months and zero flow for two months.

- In the next five years, the District will be installing structural features that will allow the Loxahatchee Slough to be connected to the regional system, thereby enhancing the District's ability to provide additional water to the NW Fork. This effort will be performed in phases with the first phase focused on establishing a meaningful conveyance of water (10-20 cfs) from the City of West Palm Beach's Grassy Waters Preserve (a.k.a. West Palm Beach Water Catchment Area) to the C-18 basin within the next two years (see MFL Recovery and Prevention Strategy).
- In addition, the District will research the feasibility of installing one or more salinity barriers downstream from Kitchen Creek, to retard saltwater intrusion during dry periods. Installation of this barrier may reduce the volume of flow that is needed during dry periods to maintain a bottom salinity of 2 ppt at river mile 8.1. This salinity barrier will include a by pass conveyance to both reduce the harmful effects of large flows during high rainfall events and maintain the current level of drainage within the basin.

Technical Relationships Considered to Define Significant Harm for the Southwest Fork and Estuary

The Southwest Fork

Description

Freshwater flows delivered to the Southwest Fork of the Loxahatchee Estuary originate primarily from the C-18 Canal and its outlet control structure, S-46. The Southwest Fork drains an area of approximately 106 sq. miles located in northeastern Palm Beach County. (**Figure 4**). C-18 also receives flow several other smaller creeks (Sims Creek, Jones Creek). The Southwest Fork has been heavily altered, dredged and channelized (McPherson *et al.* 1982) and is controlled by a large automated gated structure known as S-46. Salinity within this area of the estuary is influenced primarily by flows discharged from S-46 (FDEP, 1998).

Historically the C-18 basin included the remnants of the Hungryland Slough and Loxahatchee Slough, which historically fed the NW Fork of the Loxahatchee River. This area was characterized by sheet flow to the north with poorly defined drainage patterns. In 1959, the C-18 canal was constructed through these natural wetland areas to provide increased flood protection for agriculture and new residential development within the basin. As discussed in other sections of this report, construction of C-18 resulted in redirecting water that originally flowed from the Slough to the NW Fork of the River to the Southwest Fork where it could be discharged to tide through S-46.

Water Resource Functions Provided by C-18 and S-46

The C-18 Canal and S-46 control structure have basically three primary functions:

1. To provide flood protection and drainage for the C-18 basin
2. To augment flows to the NW Fork of the Loxahatchee River through C-14 and G-92

3. To maintain groundwater elevations southwest of S-46 to prevent saltwater intrusion of local groundwater sources
4. And provide groundwater recharge for local utilities.

Excess water in the basin is discharged to Loxahatchee estuary via C-18 and S-46. Water supply to the NW Fork of the Loxahatchee River is made by way of G-92 and canals of the South Indian River water Control District (SIRWCD).

Flood Control Function

The S-46 structure is a reinforced concrete, gated spillway located on the C-18 canal with discharge controlled by three stem operated, vertical lift gates. The gates are automatically controlled so that the operating system opens or closes the gates in accordance with the operational criteria discussed below. The S-46 structure is located on Canal 18, about 0.5 mile east of the Florida Turnpike and maintains optimum upstream water control stages in Canal 18. The structure is designed to pass 50% of the Standard Project Flood without exceeding the upstream flood design stage (**Table 17**); restrict downstream flood stages and channel velocities to non-damaging levels; and prevents saline intrusion of local groundwater. S-46 is operated to maintain an optimum headwater elevation of 14.8 feet, when sufficient water is available to maintain this level, through automatic operation of the gates. The automatic controls on the gates function as follows:

- When the headwater elevation rises to 15.0 feet, the gates will open at a speed of 0.4 inches per minute.
- When the headwater elevation rises or falls to 14.8 feet, the gates will become stationary.
- When the headwater elevation falls to 14.5 feet, the gates will close at 0.4 inches per minute.
- During major storm events, the gates are operated manually to lower and maintain a headwater stage of 12.8. A major storm event is defined as any event which causes a tailwater stage at the C-18 Weir to rise above 17.6 feet.
- During large eastern basin storm events, the gates are operated manually to lower and maintain an S-46 headwater stage of between 13.0 to 14.0 feet. A large eastern basin storm event is defined as one that prevents adequate gravity drainage of the agricultural area at the junction of C-18 and the Turnpike. This operation will be maintained for 24 hours (or longer if conditions warrant).

Structure S-46 also supports a water level upstream and downstream remote digital recorders, gate position recorder, and a rain gauge remote digital recorder.

Table 17. C-18 Flood Discharge Characteristics

Parameter	Design	Standard Flood Project
Discharge rate	3,420 cfs	3,420 cfs
Standard Project Flood	50% SPF	100% SPF
Headwater Elevation	12.8 ft NGVD.	16.4 ft. NGVD
Tailwater Elevation	2.2 ft.	2.2 ft.
Type Discharge	Uncontrolled free	Controlled free

Water Supply Function:

The water supply functions of the C-18 basin are summarized in part in the draft NPBC Comprehensive Water Management Plan (in prep). These include:

- Providing a base flow of 65 cfs over the Lainhart Dam to the NW Fork of the Loxahatchee River
- Providing supplemental water to the Loxahatchee Slough to maintain water levels that do not fall more than 0.5 ft. below the identified slough hydroperiod target.
- Providing up to 5 cfs of base flow to the Southwest Fork of the Loxahatchee River through S-46 to aid in water quality improvement for C-18 and the downstream estuary.
- Providing recharge for local water supply utilities. This includes providing up to 20 cfs (13 mgd) of recharge to the Golf Digest surface water management system to protect wetlands, up to 20 cfs (13 mgd) of recharge for the Town of Jupiter to prevent saltwater intrusion of local ground water supplies, and up to 23.5 cfs (14 mgd) of recharge for SeaCoast Utilities (Table 17).

Current water use permits for seacoast Utility and the Town of Jupiter limits withdrawals from the C-18 canal when stages in the canal fall below 14.0 ft. NGVD. In addition, special conditions of the Golf Digest environmental resource permit include the

Table 18. SeaCoast Utility Authority estimated water supply demands with and without the Golf Project (Source NPBCCWMP, in prep)

Wellfield Name	Without Golf Digest (MGD)	With Golf Digest (MGD)
Hood Road	10.4	13.8
North Palm Beach	2.7	2.5
Burma Road	2.4	2.9
Palm Beach Gardens	4.3	4.3
<i>Total</i>	<i>19.8</i>	<i>23.5</i>

requirement to cut off flows to the Golf Digest project when C-18 drops below 14.0 ft. NGVD. The average daily withdrawal rates for Seacoast Utility Authority authorized by water use permit number 50-00365-W are shown **Table 18** above.

The Southwest Fork is important for navigational and recreational use because it provides access to local marinas and private homes. It also provides a mixing zone for discharges from C-18 Canal before they reach more sensitive grass beds and oysters located further downstream.

Surface Water Quality

Surface water quality within the estuary is quite variable, and is highly dependent on the mix of saltwater and freshwater. Sea water is saline, typically very clear, fairly high in dissolved oxygen, and low in nutrients and bacteria. Conversely, freshwater discharges to the estuary from inland sources typically have less clarity, are lower in dissolved oxygen content, and contain greater concentrations of nutrients and bacteria counts. Therefore, water quality varies at different points within the estuary. The water quality recorded on a high tide during the dry season can be quite different from the quality of water recorded on an outgoing tide during a high rainfall period.

Nine water quality sampling stations located in the Sub-basin 3 have been monitored

since the early 1970s. The information available from this data can be useful in presenting a composite picture of water quality. Salinity typically ranges from nearly 30 parts per thousand (ppt) on the eastern margin of the sub-basin, to below 15 ppt at the upper reaches of the three river forks within the basin. The clarity of water in the estuary is generally good, with turbidity averaging 3 milligrams per liter (mg/l), color around 50 and secchi disk measurements greater than 1.3 meters. Average dissolved oxygen concentrations are also good (6 mg/l or above). However, biochemical oxygen demand values tend to be increasing toward a watershed high of 2 mg/l. Levels of fecal coliform bacteria also have increased from the 1970 levels. Total nitrogen readings have nearly doubled to concentrations above 1.2 mg/l, and sometimes exceed 2 mg/l. The composite Florida Water Quality Index for these estuarine stations has fallen from a good rating recorded in the 1970s to a fair rating in recent years.

There is an absence of data collected during times of discharge to the estuary (Sub-basin 3). It is commonly believed, and supported by some information, that the water quality degrades when velocities in the canal cause scouring of the bottom sediments and mixing during discharge events. Large volumes of water discharged to tide after a major storm event results in very high nutrient and organic loadings entering the estuary.

Loxahatchee Estuary

General Features and Importance to the Region

The estuary is centrally located within the Loxahatchee River watershed (**Figure 2**) and receives freshwater from three major tributaries of the Loxahatchee River and seawater from the Jupiter Inlet. The mixing of seawater and freshwater creates the brackish water characteristic of the estuary. The estuary contains seagrass beds, tidal flats, mud and sand bottom communities and oyster beds. The tidal and freshwater flows determine bottom sediment characteristics and sustain the several distinct biological communities. Seagrass beds and oyster bars grow where suitable undisturbed bottom sediment occurs and where tides maintain adequate salinity and flow conditions (FDEP, 1998). Seagrass covers approximately 5 percent of the water area. Seagrasses are found primarily in the central embayment fringing the shoreline, forming extensive beds southwest of the sandbar and in shoal water at the mouth of the North Fork, as patches between Dolphin and Marlin canals, and patches between the mangrove islands and the Alternate A1A bridge. (Antonini, *et al.* 1998; Vare *et al.* 1985). Seagrass distribution may vary considerably from year to year.

The Loxahatchee River Estuary has an average depth of about 4 feet. Estuarine conditions extend from the Jupiter Inlet to about 5 miles up the Southwest Fork, 5 miles up the North Fork, and (for this analysis) approximately 5 to 10 miles up the NW Fork. Sandbars and oyster bars in the central embayment (**Figure 2**) of the estuary are occasionally exposed at low tide as is much of the forested flood plain in the NW Fork. Some of the deeper areas present within the estuary are a result of dredging (Russell and McPherson 1984).

Major issues

Manatee Usage

The Florida manatee (*Trichechus manatus*) is an important marine mammal that lives in the Loxahatchee River system. The Marine Mammal Protection Act of 1972 and the Endangered

Species Act of 1973 protect manatees at the federal level. At the state level they are protected by the Florida Manatee Sanctuary Act of 1978, which establishes the entire state as a refuge and sanctuary for manatees. Manatees are also protected by the Loxahatchee River-Lake Worth Creek and Indian River Lagoon Aquatic Preserve Management Plans (Law Environmental Inc. 1991b).

The Loxahatchee River (including NW and SW Forks) is considered a Priority 1 area, based on recognized manatee use, because this area has a history of use on a regular basis by large numbers of manatees within the region. The concern has been raised that alteration of the minimum flows of freshwater systems could contribute to aquatic plant community alterations and decline, a reduction in water quality and/or a reduction in adequate levels of warm water that manatees require. (Kipp Frohlich, 1997 personal communication)

Use of the Loxahatchee River by manatees is well documented. Several mothers and calves have been observed apparently drinking fresh water at the S-46 Structure during dry periods. This area may also be an important nursery area and mating behavior has been observed in this vicinity (Law Environmental Inc. 1991b). Although manatees can often be seen skimming fresh water off the surface and congregating at spillways and other freshwater sites, ingestion of freshwater in this manner is not a requirement. Manatees normally obtain sufficient amounts of water from the vegetation they eat. (Mary Morris, 2000, personal communication.

In general, manatees avoid areas with the greatest boat traffic. They also tend to migrate upstream into Jonathan Dickinson State Park during rough weather. Primary areas of manatee use include the Southwest Fork near S-46, the lower North Fork, Jupiter Inlet (river mouth) and residential canals. Nearby Jupiter Sound is a seasonally important feeding ground. The largest concentrations of manatees occur in October, January, & December (Law Environmental Inc. 1991b).

Brine Releases to the Southwest Fork

The Town of Jupiter Water System operates a reverse osmosis water treatment plant that produces concentrated brine solution as a waste product and discharges this brine to the C-18 Canal downstream of the S-46 structure. The current plant is designed to process 2 MGD of water obtained from the Floridan aquifer and discharges an average of 1.5 MGD of brine to C-18. This water flows downstream through S-46 to an area of Class II surface waters (shellfish harvesting), although no harvesting is conducted now. Total ammonia has ranged from 6-7mg/l with a max. of 15 mg/l. (Tim Powell, 2000, Personal Communication)

The current permit is set to expire in June 2001. In the new permit application, the Town of Jupiter Water System is requesting to expand plant capacity to 4 MGD, increase the amount of brine discharge to 3 MGD and expand the mixing zone to 1000 ft on either side of the discharge. Nitrogen levels have increased in the vicinity of the discharge to the extent that FDEP wants this facility to propose a monitoring station for a nonpoint discharge, which would require a TMDL allocation (Tim Powell, 2000, Personal Communication).

Additional brine effluent is released by the Village of Tequesta Water Treatment Plant near the northeast side of the US#1 Bridge, just downstream of the embayment area. This release is relatively new and does not appear to be causing any problems due to the presence of strong currents in the area from the inlet.

Water Quality.

The District has responsibility to ensure that the establishment of MFLs improves, or at least does not hinder, the ability to meet applicable water quality standards and provide water of adequate quality to meet the needs of man and nature. The Loxahatchee-Lake Worth Creek Aquatic Preserve has Class II and III waters. Outstanding Florida Waters occur within Jonathan Dickinson State Park and along the Wild and Scenic segments of the river. C-18 Canal is a Class I water body because it is used as a source for public water supply. These classifications are summarized in **Table 12**.

Although water quality in this system generally meets, applicable standards, problems occasionally occur in the river and estuary with respect to dissolved oxygen levels, coliform bacteria and total nitrogen (FDEP 1996; 2000).

Providing water from the Loxahatchee Slough to the Loxahatchee River during the dry season to meet MFL requirements is expected to benefit water quality conditions in the river and estuary. Water from the slough should be of better quality (lower levels of dissolved and suspended solids, nutrients and pesticides and higher levels of dissolved oxygen) than water from tributaries such as Cypress Creek and Hobe Groves Ditch. During the dry season, flow from the slough will comprise a larger proportion of total flow to the river and hence can be expected to result in overall water quality improvement relative to historic conditions. The resulting reduction in nutrient, pesticide, and total coliform concentrations in river water, coupled with increased freshwater flow during the dry season, will also benefit the downstream estuary. Providing a minimum freshwater flow to the C-18 Canal will ensure that brine discharges are sufficiently diluted before they can impact biological resources in the estuary.

Water Supply.

During wet periods, the C-18 Canal is used as a source of recharge for the Town of Jupiter and Sea Coast Utilities. The downstream (estuarine) portion of the Southwest Fork is used for disposal of brine effluent from the water treatment plant. Sufficient water flow needs to be maintained in this system to meet water supply requirements and also to provide for dilution of the brine effluent to avoid toxicity problems at the point of discharge.

Two primary sources of water are used for water supply and agricultural irrigation within this watershed -- withdrawals from the surficial aquifer; and withdrawal from the Floridan aquifer system

- Withdrawals from the surficial aquifer system influence water levels in adjacent wetland systems as well as groundwater discharges to the river and estuary.
- Withdrawals from the Floridan aquifer system do not influence water flows to the river or estuary directly but create associated water quality problems due to the need for brine disposal.
- Water quality data have been compiled and analyzed by the Florida DEP to determine current status and trends in this system. Results of this analysis indicate that water quality in this system is generally adequate to meet the designated uses, which include the following

- Public water supply (Class I) use for the C-18 canal upstream of the S-46 salinity control structure
- Fish and wildlife habitat/natural systems (Class III) use in the NW and North Forks and
- Shellfish harvesting (Class II) use in the estuarine portions and Aquatic Preserves.

A few exceptions have been noted where these standards are not met periodically at some locations:

- Low levels of dissolved oxygen occur periodically in some parts of the system
- Total nitrogen concentrations are elevated within the estuary, at least partly attributable to brine disposal
- Total coliform concentrations exceed water quality standards in the NW Fork near Jonathan Dickinson Park, North Fork near the Girl Scout Camp, and at Dubois Park near the Jupiter inlet.
- Rapid changes in salinity and increased turbidity are associated with high volume releases of freshwater from C-18 Canal during and after severe storm events.

Factors to consider for protection of estuarine resources, especially in the Southwest Fork include the need to provide adequate flow to produce a freshwater plug in the embayment area that will reduce saltwater intrusion up the NW Fork during periods of drought (Law Environmental 1991). Adequate freshwater flow (min/max) should also be provided to maintain local seagrass communities, invertebrates and fish populations. Monitoring of proposed dredging in the inlet and the embayment area is needed to ensure that these modifications do not result in further salt water intrusion. Brine disposal in the Southwest Fork results in high levels of nitrogen, to the extent that the Florida DEP may require a Total Maximum Daily Load (TMDL) for nitrogen loads

Biological Resources, and Responses to Freshwater Flow.

The Loxahatchee estuary supports a diverse, although not especially numerous assemblage of fishes and invertebrates. Fishes and plankton respond to changes in salinity in the water column, whereas the survival of benthic species, such as shrimp, insect larvae, worms, oysters and seagrasses depends on salinity conditions at the bottom or within the substrate. These benthic organisms may form a primary food source for fishes and are unable to migrate away from adverse conditions. The population density, diversity and species composition of benthic communities therefore provide a better indicator of average salinity conditions with a given segment of the estuary.

Flow Salinity Requirements

As described above, due to the presence of a saltwater wedge, salinity at the bottom of the estuary is often significantly higher than salinity at the surface or within the water column. A low salinity (less than 5 ppt) area always exists at some point within the NW Fork and is often present in the upper reaches of the North Fork River and the C-18 Canal. The wider areas of the NW Fork and North Fork, Southwest Fork and Central Embayment may experience salinity

conditions in the range from zero (during high discharge periods) to 35 ppt (during periods of no discharge). Throughout much of the Loxahatchee estuary, bottom salinities generally remain above 25 ppt (see **Table 19**).

Table 19. Summary of salinity conditions within the Loxahatchee estuary during high, moderate, and low volume discharges of freshwater (based on Russell and McPherson 1984)

<p>Extreme Wet Period (840 cfs in NW Fork, Following Hurricane Dennis 1980)</p> <p>Top salinities</p> <ul style="list-style-type: none"> North fork and central embayment -- range from 15 to 30 ppt. NW fork -- range from 1-5 ppt SW Fork -- less than 1 ppt <p>Bottom salinities --High tide</p> <ul style="list-style-type: none"> Most areas range from 25 -35 ppt. South Fork and NW Fork upper reaches -- salinities are 20-25 ppt <p>Bottom salinities -- Low tide</p> <ul style="list-style-type: none"> South fork bottom salinities are 15-20 ppt NW fork range from 10 ppt to 35 ppt. <p>Typical wet season (100 cfs flow from North Fork)</p> <p>Top salinities</p> <ul style="list-style-type: none"> NW Fork. ranges from 10 to 35 ppt Central embayment ranges from 25 to 35 ppt SW fork is 10-15 ppt North Fork is 30 ppt or higher <p>Bottom salinities high tide</p> <ul style="list-style-type: none"> NW fork ranges from 10 to 35 ppt SW fork is 10-15 ppt North Fork is 35 ppt or higher <p>Bottom salinities at low tide</p> <ul style="list-style-type: none"> NW fork range from 25 - 35 ppt. SW fork is 30-35 ppt North Fork is 30-35 ppt <p>Some areas of the bottom experience rapid changes in salinity during the course of a tidal cycle.</p> <p>Typical dry season (30-60 cfs flow from North Fork)</p> <p>Top salinities</p> <ul style="list-style-type: none"> NW fork range from 20 -30 ppt Central embayment is 30 -35 ppt at low tide Central embayment is above 35 ppt at high tide. North Fork is above 35 ppt at high tide. South Fork ranges from 30-35 ppt <p>Bottom salinities</p> <ul style="list-style-type: none"> North Fork and South Fork are 25 ppt and above Most of the estuary is above 35 ppt at high tide. South Fork ranges from 30-35 ppt <p>Extreme Dry Period (9 cfs flow from North Fork)</p> <ul style="list-style-type: none"> Central embayment is above 35 ppt. NW and Southwest Forks range from 30 ppt to above 35ppt

Summary of Analysis for the Southwest Fork and Estuary

- Because the system receives some freshwater flow at all times, low salinity habitats are continuously available at various locations in the remaining natural tributary streams.

- Based on experience gained from studies conducted in other estuaries, District staff propose that a loss of freshwater flow or elimination of low salinity habitat, occurring during two successive years, would constitute significant harm to the Loxahatchee Estuary. Such conditions are not likely to occur under any present or proposed future management scenarios.
- Freshwater flows to the estuary need to vary seasonally to reflect natural patterns of rainfall and river flow and provide seasonal ranges of estuarine conditions that are needed to support euryhaline species and for larvae and juveniles of marine species that use this estuary as a source of food and protection during all or part of their life cycle.
- High salinities (above 30 ppt) should not be maintained for long periods of time (more than 4-6 weeks at a time) in the North Fork, NW Fork, Southwest Fork or Central Embayment. Although high salinities help to establish and maintain seagrass communities, these conditions may also lead to decline or elimination of oyster and perhaps other estuarine benthic plant and animal communities.
- The occurrence of hypersaline conditions or toxicity due to ion imbalance, which may occur due to discharges of effluent from desalination, should be avoided in the Southwest Fork by maintaining a constant minimum flow of 5 cfs through the S-46 structure, during periods when the reverse osmosis water treatment plant is in operation.
- Minimum flow criteria that are established to protect the river will also provide flows necessary to avoid significant harm and maintain viable benthic and fish communities in the estuary during dry periods.
- During high volume discharges of fresh water from the NW Fork of the River (up to 840 cfs) bottom salinity in the lower portion of the NW Fork and Central Embayment remain above 25 ppt, indicating that seagrass and oyster communities in these areas can survive during such events. Discharges of larger volumes of freshwater, especially from C-18 Canal through the SW Fork are likely to result in mortality of these communities and should be avoided, when possible.
- Further research is needed to establish seasonally-varying patterns of freshwater delivery and maximum discharge criteria that are needed to protect and improve estuarine resources.

Proposed MFL Criteria for the Southwest Fork

Based on the information provided above, the following minimum flow criteria are proposed for the Southwest Fork of the Loxahatchee Estuary.

During dry periods, when the Town of Jupiter's reverse osmosis water treatment plant is in operation, a constant minimum flow of 5 cfs is recommended through the S-46 structure to reduce the problem of hypersaline conditions, toxicity, or ion imbalance that may result from the discharge of brine effluent downstream of S-46 .

MFL RESEARCH NEEDS FOR THE LOXAHATCHEE RIVER AND ESTUARY

Scope and Purpose

In the development of this draft document, District staff relied primarily on existing monitoring and research data to identify technical relationships between flow, salinity and observed impacts to the river's biological resources to establishing an initial MFL for the NW and Southwest Forks of the Loxahatchee River and estuary. District staff did not have the opportunity to conduct additional monitoring or research within the water body to validate and/or refine the proposed minimum flow regime or duration criteria presented in this report. For this reason, the research projects listed below are proposed over the next several years to collectively evaluate and/or refine the proposed MFL flow target and duration criteria as necessary.

A major focus of this research will be to identify a science-based estimated number of days that surface water flows in the NW Fork can remain below the proposed minimum flow target of 68 cfs (as measured at the Lainhart Dam), without causing significant harm to the upstream cypress swamp floodplain community. Furthermore, the proposed projects will provide information that can be utilized by regulatory agencies to make informed decisions regarding the effects of the existing and proposed modified hydrologic regimes, on the natural system of the River, and potential future management efforts. The following provides a summary of proposed research projects recommended by staff for fiscal year 2001-2002 to refine or verify proposed MFL criteria for the Loxahatchee River and Estuary.

Tributary Flow Monitoring

The District will establish real-time telemetry surface water flow monitoring stations within the major tributaries to the NW Fork (i.e. Cypress Creek and Kitching Creek) to obtain data that will assist in efforts to more accurately determine total freshwater flows to the NW Fork. From these data District staff will be able to develop a simplified water budget for the Loxahatchee River system.

Ground Water/Soil Salinity Monitoring

The District will establish groundwater and soil monitoring stations within the floodplain of the NW Fork to identify locations of saline groundwater and soil, and to quantify the amount of saline contamination. Data collected from this monitoring will be specifically correlated with other River monitoring and research data (i.e. flow data and surface water, salinity data, vegetative data) to refine the relationships between flow, salinity and the cypress wetland community.

Watershed Modeling

The District will develop a watershed management plan for all tributaries that drain into the Loxahatchee River. This plan will be initiated by expanding the current *Basin Assessment and Hydraulic/Hydrologic Study of Cypress Creek/Pal –Mar and the Groves* project to develop a Cypress Creek Basin watershed model, that could be utilized for other drainage basins within the Loxahatchee Watershed. This watershed modeling effort would be the first step to: 1) develop a sub-regional hydrologic model that addresses existing Water Use Permits for the Loxahatchee Watershed and their effect on providing minimum flows for the NW Fork; 2) provide hydrologic studies of drainage basins that discharge to the Loxahatchee River, to determine which basin is the best source of water to provide minimum flows to the River and Estuary; and 3) determine the relationship between the Loxahatchee River, Loxahatchee Slough and the surficial aquifer.

River Corridor Vegetation Monitoring

The District will develop a research and monitoring program to more thoroughly investigate the relationship between the upstream movement of the saltwater wedge and adverse impacts to the floodplain cypress wetland community on the NW Fork and Kitching Creek. The program will establish vegetative transects to document and identify vegetative species salinity level and duration tolerances; how different salinities affect physiology; growth and recruitment; and the short-term and long-term change(s) in relation to flow and salinity. Data collected from this monitoring will be specifically correlated with other River monitoring data (i.e. flow data and surface water, groundwater and soil, salinity data) to refine the relationships between flow, salinity and the cypress wetland community.

Estuary Research

A major assumption in the development of the MFL was the use of the Valued Ecosystem Component (VEC) method to establish the MFL based on protection of upstream cypress communities. A missing piece of information that needs to be addressed is what is the effect of the proposed minimum flow regime on the nursery function and extent of oligohaline habitat as well as other downstream estuarine or marine species? During the next fiscal year, District staff will review and analyze existing water quality and biological data (fish larvae, zooplankton, benthic invertebrates) collected from the river from 1986-1988 to elucidate relationships that exist between river flow and biological response. Additional monitoring may also be necessary to measure the effect of the proposed MFL on these resources.

GENERAL RECOMMENDATIONS

The criteria developed in this document should be used as the basis for District rule development and to incorporate monitoring of the MFL criteria as a factor to be considered in the issuance of Consumptive Use Permits, both individually and cumulatively, within the LEC Planning Area and, more specifically, within the Northern Palm Beach County water supply planning area.

These criteria will need to be reviewed, and perhaps revised, as: 1) additional data becomes available through future research and monitoring projects; 2) as the prevention and recovery strategies are implemented; 3) as environmental conditions may change over time (i.e. due to sea level rise or climate change), or 4) as additional experience is gained through the Consumptive Use Permitting process.

The following additional research and monitoring projects that should be considered for future refinement of the MFL criteria for the Loxahatchee River. These studies have also been specifically identified by Loxahatchee regulatory agencies and interest groups, as necessary for future management efforts:

- Real-time salinity monitoring in the NW Fork
- Feasibility study for salinity barrier engineering design/modeling for the NW Fork
- Expand routine water quality monitoring network to include Loxahatchee River tributaries
- Develop a sub-regional watershed model that addresses existing water use permits and their effects on the NW Fork
- Develop a rainfall-based water delivery system model for the Loxahatchee Watershed

MFL RECOVERY AND PREVENTION PLAN

Section 373.0361, F.S. requires that each regional water supply be based on at least a 20-

year planning period and include (a) water supply and water resource development components, (b) a funding strategy for water resource development projects, (c) MFLs established within the planning region for identified priority water bodies, (d) development of a MFL recovery and prevention strategy, and (e) technical data and information supporting the plan.

Section 373.0421, F.S., requires that once the MFL technical criteria have been established, the Districts must develop and expeditiously implement a recovery and prevention strategy for those water bodies that are currently exceeding, or are expected to exceed, the MFL criteria. Section 373.0421(2), F.S., provides the following in part:

The recovery or prevention strategy shall include phasing or a timetable which will allow for the provision of sufficient water supplies for all existing and projected reasonable-beneficial uses, including development of additional water supplies and implementation of conservation and other efficiency measures concurrent with to the extent practical, and to offset, reductions in permitted withdrawals, consistent with the provisions of this chapter.

MFL Recovery and Prevention Strategy Implementation Policies

Historical information provided in this report indicates that the proposed minimum flow criteria are exceeded approximately 50% of the time under current conditions. Review of existing information indicates the proposed MFL cannot be achieved immediately because of ineffective water distribution infrastructure and the lack of adequate regional storage facilities. These storage and infrastructure shortfalls will be resolved through water resource development and water supply development projects, construction of facilities, and improved operational strategies that will increase the region's storage capacity and improve the existing delivery system. Planning and regulatory efforts will, therefore, include a programmed recovery process that will be implemented over time to improve water supply and distribution to protect water resources and functions. Development of a MFL Recovery Plan for the Loxahatchee River and Estuary is underway and will be incorporated into the planning process of the *Northern Palm Beach County Comprehensive Water Management Plan* as well as the *LEC Regional Water Supply Plan*. Appropriate technical analyses are also being conducted to determine the possible water supply implications of the proposed MFL technical criteria on urban and agricultural users. These results will be integrated into the final *Northern Palm Beach County Comprehensive Water Management Plan* analysis with appropriate implementation measures developed consistent with Section 373.0421 F.S. The recovery process includes the following:

- Necessary structural solutions for the recovery and prevention plan will be provided in the form of a list of the various water resource development projects and anticipated completion dates for phasing in these projects as identified in the *Northern Palm Beach County Comprehensive Water Management Plan*. These projects will provide the additional water to meet the proposed MFL target and water reservations.
- If necessary to prevent the MFL criteria from being exceeded, demand management cutbacks for recovery during drought conditions will also be identified (e.g., phased water shortage restrictions to prevent significant or serious harm). *The Northern Palm Beach County Comprehensive Water Management Plan* does not propose the use of the Water Shortage Plan as a MFL recovery strategy. However, when a drought occurs, the District will rely upon the Water Shortage Plan, as necessary, to address regional water availability. This strategy is discussed below:

- To the extent practicable, the District shall implement water deliveries to reduce or prevent the MFL criteria from being exceeded. Operational guidelines necessary for implementation of water supply deliveries to achieve MFLs, in concert with meeting other required water demands, will be identified. However, water deliveries to prevent the MFL criteria from being exceeded will be given priority consideration over deliveries for other purposes.
- Before considering reduction in permitted withdrawals in a recovery and prevention strategy, all practical means to prevent reductions in available water supplies for consumptive use shall be explored and implemented. When determining whether reductions in existing legal uses are required, the following factors shall be considered:
 - The extent of MFL shortfall directly caused by existing legal uses
 - The practicality of avoiding the need for reductions in permitted supplies, including structural and operational measures, by maximizing the beneficial uses of the existing water source
 - The risk of significant harm resulting from the existing legal use in the interim period before the recovery strategy is fully implemented.

Proposed MFL Recovery Plan for the Loxahatchee River and Estuary

The following provides a summary of the District's proposed phased MFL Recovery Plan for the Loxahatchee River and Estuary.

Phase 1 (April 2001- April 2002)

District staff will work to identify specific improvements that can be implemented within one year (by April 2002) to deliver an additional 10 to 20 cfs to the NW Fork of the Loxahatchee River during dry conditions. The ability to provide water from the West Palm Beach Water Catchment Area (WPB WCA) to the NW Fork of the Loxahatchee River (NWFLR) without significantly lowering the stage within the Water Catchment Area is severely limited by the City's current pumping capacity from the L-8 Canal into the M-Canal (and subsequently into the WPB WCA). Based on recent observations and depending on the severity of the dry conditions (normal dry season versus drought) the influent capacity only exceeds demands by 10 to 20 cfs. During this period the District will work with Palm Beach County and DOT to:

- Install new culverts under the entrance road into the city of West Palm Beach's Water Catchment Nature Center.
- Provide needed repairs to the Lainhart and Masten dams
- Perform maintenance consisting of removal of exotic vegetation, maintenance excavation and grading to clear out obstructions and allow approximately 20 cfs of flow from the Eastern perimeter canal to the three western 72-inch diameter culverts under North Lake Boulevard.
- Evaluate the constraints imposed by ground surface elevations, existing roads, existing buildings, and existing control structures on the ability to route water from the north side of North Lake Boulevard (at the existing three 72-inch diameter culverts and eastward) to the box culverts under the Bee Line Highway (SR 710). This includes evaluating both the constraints and conditions of Control 5 (controls flow of water from North Side of North Lake Boulevard to the East).

- Completion of the L-8 Reservoir Pilot study

Phase 2 - Three Years (April 2001 through March 2004)

Implement improvements to improve the flow capacity for both dry and wet conditions:

- Obtain permit and construct Loxahatchee Slough structure (G-160) to increase the District's ability to store water within the slough for the dry season.
- Increase flow capacity from the M-Canal to the three existing 72-inch diameter culverts by removing biomass accumulation and establishment of canoe paths which will provide a preferential flow path within the West Palm Beach Catchment Area to provide approximately 30 cfs of flow capacity to the Loxahatchee slough and the NW Fork of the Loxahatchee River.
- As required, modify existing structures to provide conveyance and water quality enhancement (North of North Lake Boulevard) including:
 - Modification or removal of Control 5
 - Construction of a spreader swale north and parallel to North Lake Boulevard
 - Removal, breaching, or construction of additional culverts through berms or other obstructions
 - Construction of an enhanced flow way and preferential flow path as need to accommodate both the dry and normal wet weather flows and large storm water events without significant damage to the flow way area while maintaining the required level of drainage and flood protection.
- As part of the CERP planning process, complete project management plans (PMP) and project implementation reports (PIR) for water supply projects that will provide addition flow and water storage capacity for the Loxahatchee watershed.

Phase 3 - Five Years (April 2001 through 2006)

Improvements to substantially increase the sub-regional conveyance capacity and provide a water distribution system for the final water distribution system required by both the Comprehensive Everglades Restoration Program (CERP) and the Lower East Coast Regional Water Supply plan (LECRWSP).

- Construction of the M-Canal pump structure (C-2) and associated canal conveyance improvements
- Construction of the North Lake Blvd. culverts and gates (G-161) and enhanced flow way

Phase 4 - CERP (April 2001 through 2021)

Improvements to substantially increase sub-regional storage capacity and expand the water distribution system to meet the year 2050 needs.

- Construction of WPB Water Catchment Area perimeter canal improvements as required

- Construction of L-8 reservoirs (48,000 ac-ft additional storage)
- Construction of local ASR wells (50 MGD injection capacity)
- Construction of pumps to capture J.W. Corbett WMA runoff for storage within Loxahatchee Slough.